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Ground-Water Monitoring Guidance for Owners and Operators of Interim Status Facilities

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This guidance document represents the Agency's interpretation of the ground-water monitoring requirements imposed upon hazardous waste management facilities which have achieved interim status in accordance with Section 3005(e) of the Resource Conservation and Recovery Act. The bases of this document are, therefore, regulations in 40 CFR Part 265, Subpart F, as promulgated on May 19, 1980, as amended on Jaunary 11, 1982.

Section 1 of the document discusses the purpose and scope of the ground-water monitoring requirements, presenting the rationale and the policy issues for a better understanding on the part of the facility owner or operator. Section 2 discusses the detection program, identifying informational needs for monitoring well location and design, and methodology for sampling, analyses, recordkeeping, reporting, and other specific implementation issues. Section 3 is devoted to the assessment program.

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1-a

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DRAFT

GROUND-WATER MONITORING
GUIDANCE FOR OWNERS
AND OPERATORS OF INTERIM STATUS
FACILITIES

Instructions for complying with 40 CFR Part 265, Subpart F.

OFFICE OF SOLID WASTE AND EMERGENCY RESPONSE

U.S. Environmental Protection Agency
Washington, D.C.

1983
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Preface

This guidance document represents the Agency's interpretation of the ground-water monitoring requirements imposed upon hazardous waste management facilities which have achieved interim status in accordance with Section 3005(e) of the Resource Conservation and Recovery Act. The bases of this document are, therefore, regulations in 40 CFR Part 265, Subpart F, as promulgated on May 19, 1980, as amended on January 11, 1982. This document is meant to be used by the regulated community in implementing these requirements as they pertain to the particular circumstances. In no way is this document to be used as a regulation or as an amendment to existing regulations. It is meant only to offer assistance to owners or operators of interim status facilities as to possible means of compliance with Subpart F.

This is a draft guidance document. Readers are encouraged to communicate with EPA Regional Office representatives or with George Dixon (OSWER, Headquarters), any comments, reactions and criticisms stemming from the use of the document.

This document will, when necessary, be periodically revised to accurately reflect 40 CFR Part 265, Subpart F. In its continuing efforts to improve all its regulations the Agency has embarked upon several activities which upon their completion may lead to regulatory amendments. Specific to these ground-water monitoring requirements are two evaluation efforts which may result in amendments to Subpart F and revisions to this guidance document.

The first of these efforts is the Ground-water Monitoring Evaluation Project. This effort involves a survey of 179 interim status hazardous waste land disposal facilities to determine the current level of compliance with the Subpart F requirements. This survey will establish a profile of the facilities utilizing detection versus assessment monitoring schemes, those claiming a full or partial waiver of ground-water monitoring requirements, and an estimate of the number of facilities not in compliance. This evaluation will also identify those regulatory provisions causing compliance difficulties as a result of either inappropriate or misunderstood requirements.

The second evaluation effort is an analysis of the statistical comparison procedure specified in §265.93. Under this effort the Agency is obtaining background ground-water quality data for indicator parameters from interim status facilities across the country to establish distributions of the concentrations of these parameters over time. With this information on actual ground-water quality the Agency will be able to estimate the number of facilties for which the specified statistical comparison procedure is appropriate and further to identify alternative data evaluation and comparison procedures for those situations where the procedures specified in §265.93 may not be appropriate. A principle component of this evaluation will be an estimate of the "false positive" and "false negative" probabilities for various statistical procedures in various circumstances of ground water quality variability over time. [This revised draft document reflects changes affecting the anticipated small sector of owners or operators who may wish to challenge the appropriateness of the specified statistical comparison procedures].

If and when 40 CFR Part 265, Subpart F, is amended as a result of these and other studies and evaluations, this document will be appropriately revised.

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GROUND-WATER MONITORING GUIDANCE FOR OWNERS AND OPERATORS OF INTERIM STATUS FACILITIES

1.0 Overview

This Manual provides guidance for owners and operators of hazardous waste land disposal facilities in complying with the interim status requirements for ground-water quality monitoring in Subpart F of 40 CFR 265, (45 Fed. Reg. 33239 et seq., May 19, 1980) (see Appendix A). These regulations require owners and operators to design and implement either a detection program at facilities not known or assumed to be significantly affecting ground-water quality or an assessment program for quantifying the ground water quality effects which have occurred. Owners or operators who assumed that ground water has been affected by the facility were provided an opportunity waive the detection program. In this case, they may enter directly into the assessment program, quantifying the extent of contamination and the rate of migration.

While these interim status monitoring programs will provide the Agency with some useful information regarding the national, regional, or industry-specific impacts of disposal on ground-water quality, the primary Agency objective is to provide specific information regarding individual facilities. In order to lessen the initial burden, a very simple detection program was devised for universal application, with diagnostic investigations performed only at those facilities which are indicated in the detection program to have significantly affected ground water. This manual discusses the objectives of the programs, the regulatory language and the Agency's associated intent, and required monitoring systems, analyses and reporting.

The guidance in this manual is applicable to EPA-administered programs. States are encouraged to develop and administer their own programs, and in accordance with RCRA Section 3006, the Agency will authorize them in lieu of the Federal program. Approved State programs may differ in style and procedure in pursuit of their "substantially" equivalent control. This manual is not necessarily applicable in such States. Owners and operators are advised to consult their EPA Regional Administrators, listed below if they are uncertain about the status of particular State programs.

EPA Regional Administrators

Region I
John F. Kennedy Bldg.
Boston, MA 02203

Region II
26 Federal Plaza
New York, NY 10007

Region III
6th& Walnut Streets
Philadelphia, PA 19106

Region IV
345 Courtland St., N. E.
Atlanta, GA 30365

Region V
230 South Dearborn Street
Chicago, IL 60604

Region VI
1201 Elm Street
First Intl. Building
Dallas, TX 75270

Region VII
324 E. 11th Street
Kansas City, MO 64106

Region VIII
1860 Lincoln Street
Denver, CO 80203

Region IX
215 Fremont Street
San Francisco, CA 94105

Region X
1200 6th Avenue
Seattle, WA 98101

The first Section of the manual discusses the purpose and scope of ground-water monitoring requirements, presenting the rationale and the policy issues for a better understanding on the part of the owner or operator. The regulations are presented, followed by commentary regarding selection of words and the intent. The Agency's current thinking regarding the value of interim status monitoring in eventual decisions on facility permits is discussed. Content and format of the required plans and schedules are discussed in this section, followed by methods for updating and revising ongoing programs, and the Agency's view of interaction with owners and operators during interim status. Section 2 of this report will discuss in detail the detection program, identifying informational needs for ground-water monitoring well location and design, methodology for sampling, analyses, recordkeeping, reporting, and other specific implementation issues. Section 3 is devoted to the assessment program.

This report is written with the assumption that the reader has read and is thoroughly familiar with the preamble to Subpart F of the Interim Status Standards. The pertinent section begins at 45 FR 33191-May 19, 1980. Readers are also referred to the Background Document accompanying the regulation, dated May 2, 1980, which is available for viewing in the Docket Room, Room S-269-C, Waterside Mall, 401 M Street S.W., Washington, D.C., 20460, or at EPA Regional Libraries.

1.1 Purpose and Applicability of the Monitoring Requirements

The purpose of any monitoring program is to provide information. The ground-water quality monitoring program of Part 265, Subpart F is designed to provide a preliminary indication of the impacts of a newly regulated group of facilities. About 4500 hazardous waste land disposal facilities, all in existence as of November 19, 1980, the effective date of the regulations, qualified for interim status under RCRA. They comprise facilities of widely differing ages and degrees of sophistication. Some have had thorough state regulatory review, others only cursory. At present, estimates vary widely regarding the numbers of these facilities which are currently affecting ground-water quality. The scope of Subpart F includes determining the drinking suitability and general quality of aquifers underlying these facilities. It includes detection of discharge to these aquifers where it is not known or assumed, and quantification where it is. It also includes establishment of the fact of "low potential for migration" from those facilities to supply wells or surface water.

The purpose of ground-water monitoring as established in the regulations is to discover the existence and magnitude of ground-water impacts from hazardous waste land disposal facilities. The purpose does not include determinations of whether or not such facilities are environmentally acceptable. Acceptability criteria will be developed as part of the permitting process.

The Agency's first-level, or immediate, objective is to determine which land disposal facilities have leaked hazardous waste or constituents into an underlying aquifer in sufficient quantities to cause a significant change in ground-water quality. The second-level objective is to acquire information at those facilities regarding the extent and nature of the ground-water impact to provide a factual basis for decisions regarding the need for changes in design or operation or for corrective action.

The interim status ground-water monitoring requirements were not designed with the primary objective of producing evidence for enforcement proceedings, nor are the programs designed to produce statistically significant national indications of the relative ground-water quality impact of different types of hazardous waste management facilities. To the extent that information generated by the program is necessary or useful as evidence or that national trends are observable, the data will be so used. However, the monitoring frequency, well location, and parameter selection requirements were not designed for support of those goals.

The monitoring requirements of Subpart F apply to owners and operators of surface impoundments, landfills, or land treatment facilities which are used to manage hazardous waste and have qualified for interim status by submission of the notification and Part A of the RCRA permit application. The Agency expects that detecting the occurrence of significant impacts will be an appropriate objective at a great proportion of the facilities; however, at those where contamination is either unlikely to have occurred or very likely to have occurred, owners or operators may have determined that the prescribed detection program is not appropriate. Owners and operators of facilities with a low potential for contaminant migration may have chosen to waive a portion of the requirements of the detection program; owners or operators of facilities with a high probability that contamination has occurred may have presumed that the detection program would indicate a significant increase) or decrease as well for pH) in the indicators, and proceeded with the assessment under the alternate ground-water monitoring system provisions of §265.90(d).

1.2 The Regulations and the Agency's Intent

The ground-water monitoring requirements are presented in five sections, numbered §265.90 through §265.94. The first establishes the requirement to design and implement a monitoring program and it provides waiver and alternate clauses where the prescribed program is inappropriate. The next two sections prescribe the sample collection system and the analyses required for the detection program. The fourth section prescribes the data evaluation process and the requirement and procedures for the assessment program. The last section contains the reporting requirements.

Portions of the text of the regulations are reproduced here, followed by interpretive language, responsive to some of the more commonly received inquiries. The full text is provided in Appendix A.

The requirement for monitoring ground water is contained in §265.90(a).

> ...the owner or operator of a surface impoundment, landfill or land treatment facility which is used to manage hazardous waste must implement a ground-water monitoring program capable of determining the facility's impact on the quality of ground water in the uppermost aquifer underlying the facility...

The key word in this section is "capable". Definitive design standards for a ground-water monitoring system which would be applicable in all anticipated situations did not prove feasible. Rather the Agency has described performance requirements in general terms with certain basic minimums. Reasonable documentation of that capability is implied. The program must have been implemented by November 19, 1981, and capable of producing a representative sample during the first quarter, or by February 19, 1982.

The ground-water monitoring requirements may be waived at certain facilities as specified in §265.90(c):

> All or part of the ground-water monitoring requirements of this Subpart may be waived if the owner or operator can demonstrate that there is a low potential for migration of hazardous waste or hazardous waste constituents from the facility via the uppermost aquifer to water supply wells (domestic, industrial, or agricultural) or to surface water.

The intent of this provision, as expressed in the preamble, is narrowly confined so as to provide relief from the monitoring requirements when, for instance, climate will not sustain leachate production or when geology will isolate produced leachate from any point of aquifer use. Public comment consistently points to the existence of extremely well protected ground water, of sites underlain by hundreds of feet of highly attenuative clays and of arid climates in which no support for monitoring rationale can be provided. The May 19, 1980 preamble discussion excludes liners, unsaturated zone monitoring, and unique waste-behavior characteristics as bases for waivers.

Although the Agency continues to expect that only a small proportion of the facilities in interim status will qualify for a complete waiver there is an increasing awareness of grounds for partial waivers in which relaxation of certain requirements may be warranted. Where those situations are waste related, such as waiving total organic halogen at facilities able to demonstrate the continued absence of organics content in the waste, the Agency will consider extending the waiver provisions as was done in the case of §265.90(e) (see preamble discussion, p. 151 below).

On January 11, 1982, the regulations were amended, by addition of §265.90(e), to extend the waiver provisions to apply to neutralization surface impoundments (see 47 FR 1254, et seq). Those facilities shown to rapidly neutralize corrosive wastes and to contain no waste exhibiting other hazardous characteristics, are now eligible to waive the ground-water monitoring requirements. The Agency has requested information on other types of facilities which can be reliably demonstrated to have low potential for migration of hazardous waste or hazardous constituents. Waiver demonstrations, of course, will be expected to conclusively indicate that partial waivers will not impede monitoring program effectiveness. The Agency expects, however, that in most parts of the United States, and for most wastes whose purity cannot be assured, owners or operators of land disposal facilities will install and operate the detection program as described in Part 265. The extent of the investigations required to substantiate the waiver demonstration may have discouraged some of the more questionable cases, since complex situations require expensive geophysical exploration which could outweigh the cost of the monitoring system.

Striving for a reasonable approach the Agency provided the waiver opportunity appropriate to the potential for migration, but chose not to include time in the criterion. The expectation was that facilities over regionally important ground-water bodies are not eligible for a waiver whenever ground-water migration will transport the introduced contaminants within geologic time. Not specifying an acceptable time frame will severely restrict the use of a complete waiver. Owners or operators should be prepared for a critical review of waiver demonstrations upon facility inspection.

Section 265.90(c) continues:

> This demonstration must be in writing, and must be kept at the facility. This demonstration must be certified by a qualified geologist or geotechnical engineer and must establish the following:
>
> (1) the potential for migration of hazardous waste or hazardous waste constituents from the facility to the uppermost aquifer, by an evaluation of:
>
> (i) a water balance of precipitation, evapotranspiration, runoff, and infiltration; and
>
> (ii) unsaturated zone characteristics (i.e., geologic materials, physical properties, and depth to ground water); and
>
> (2) The potential for hazardous waste or hazardous waste constituents which enter the uppermost aquifer to migrate to a water supply well or surface water, by an evaluation of:
>
> (i) saturated zone characteristics (i.e., geologic materials, physical properties, and rate of ground-water flow); and
>
> (ii) the proximity of the facility to water supply wells or surface water.

The waiver demonstration should be a prepared report maintained up to date at the facility. It should describe the rationale and present the evidence by which the owner or operator concludes that a lesser degree of monitoring is appropriate at the particular facility, based upon the site hydrogeology. It must be developed in sufficient detail to convince an EPA inspector of the absence of unknown hydrogeologic conditions which may serve to channel leachate. The demonstration must have been certified by a qualified geologist or geotechnical engineer who was present during field testing to supervise information gathering and who has detailed first hand knowledge of the site hydrogeology.

The detection program is also inappropriate at facilities having a very high probability of affecting ground water quality. The regulations have provided an opportunity for owners or operators who know or assume that their facility is discharging to ground water to avoid the time and expense of detection program monitoring. Section 265.90(d) [alternate ground-water monitoring system] states:

> If an owner or operator assumes (or knows) that ground-water monitoring of indicator parameters... would show statistically significant increases... he may install, operate, and maintain an alternate ground-water monitoring system (other than the one described in §§265.91 and 265.92).

It goes on to say that if the owner or operator decides to use an alternate ground-water monitoring system he must submit to EPA a specific plan for an alternate ground-water monitoring system, initiate the determinations and submit a written report, etcetera in accordance with the assessment program requirements in §265.93.

The alternate system is appropriate where existing monitoring information shows clearly, without the need for statistics, that contamination has occurred. It avoids the unnecessary delay during which background and indicator parameters are statistically compared. The owner or operator may avoid the expense and the prolonged uncertainty of operating under the detection system by going directly into the assessment program. This cooperative approach could be helpful in deciding whether enforcement actions are necessary; it is also useful to owners or operators who believe that their discharge to ground water does not threaten human health or the environment. The Agency encourages all owners and operators to implement more than the minimum acceptable program in the belief that the additional information is to their benefit.

The minimum acceptable ground-water sampling system is described in §265.91 and again, the key word is "capable".

> (a) A ground-water monitoring system must be capable of yielding ground water samples for analysis and must consist of:

(1) monitoring wells (at least one) upgradient... capable of yielding [representative background samples], and

(2) monitoring wells (at least three) downgradient... their number, locations and depths must ensure that they immediately detect any statistically significant amounts of hazardous waste or hazardous waste constituents that migrate...to the uppermost aquifer.

The wording in paragraph (2) above, unfortunately, has caused many questions, and needs clarification: locations and depths which enable timely detection are considered to comply.

As set forth in Section 2.2.4, well depths are critical to the system capability. Well clusters for monitoring at multiple depths are encouraged so that high concentrations are not masked by dilution with uncontaminated ground water entering a well intake which is too long. The detection program is focused on the uppermost aquifer, not because it is more or less worthy of protection, but rather because contamination will be more readily detectable. The words "significant" and "uppermost" should guide the owner or operator to the saturated zone most likely to exhibit the occurrence of discharge. While some perched and discontinuous water tables may be ignored without affecting system capability, samples should not be selected at sheltered points obscure to the most direct flow paths.

Sampling and analysis for the detection program is prescribed in §265.92. Paragraph (a) requires the owner or operator to prepare and follow a plan for collecting and analyzing samples. This plan is intended to standardize collection, storage and handling techniques. For instance, the temperature and containers used for storing samples for background determinations should not differ for subsequent samples. Filtration of samples warrants special consideration in plan development, because analysis for metal and other constituents are affected by filtration. The choice of sample filtration should be based on the analytical techniques, on the waste (e.g., if the facility's leachate is likely to consist of a large filterable portion, filtered samples would not be representative) and on the hydrogeologic setting; and it should be consistently used throughout the detection program.

Thirty parameters are listed in §265.92(b) for which analyses are required. The first group is the suitability parameters listed in the National Primary Drinking Water Regulations, §141.11-.16. The Agency objective in this requirement is to determine the value of the resource in terms of its drinking suitability. During the comment period, several commenters made the point that all ground water is not necessarily of equal value, and that the regulatory strategy should allow for consideration of the quality of the resource involved. Where reliable regional data and nearby public water supply systems' data for the radioactive parameters are available, these may be used to assist in the required determinations.

Analysis of the suitability parameter list also provides an initial screening of facilities in that owners and operators must identify up and downgradient wells where samples indicate that the ground water is unsuitable for drinking. Analyses is only required for the first year, although owners and operators may wish to record subsequent changes in regional suitability, especially when trends are observed.

The second required group of parameters indicates the general ground-water quality. These six parameters will be used as a base of comparison if and when a ground-water quality assessment is required. Background for these parameters must be established by quarterly analyses the first year (i.e., Feb. 19, May 19, Aug. 19 and Nov. 19, 1982); thereafter, they must be determined annually at all wells.

The contamination indicators selected for routine comparison of background and subsequent monitoring-well data are listed in §265.92(b)(3). Four samples must be taken in the first year in order to determine seasonal effects. Replicates are only required for the upgradient wells during the first year, and the initial background arithmetic mean and variance must be determined by pooling the values from the replicate measurements. Only the upgradient values will constitute background. Wells must be sampled at least twice in each succeeding year, and for each routine comparison at least four replicate measurements must be obtained for each parameter at each well.

The basis for the indicator parameter selection is the Agency's belief that significant discharges from hazardous waste management facilities to ground water will often result in an observable change in at least one of the four selected indicators: pH, specific conductance, total organic halogen (TOX) and total organic carbon (TOC). The Agency believes there is a low probability that a major discharge could occur without a significant change in at least one of the four indicators in representative ground-water samples. The rationale for employing this two level approach is that the results will be protective of health and environment and at minimum cost and disruption.

As expressed in the background document for the regulations, dated May 2, 1980, the Agency rationale was to devise a monitoring protocol that will be responsive to a large undefined set of chemical compounds at unspecific concentration levels which could only be classed in general terms such as ionic, nonionic; organic, inorganic; or dissolved or suspended in the ground water.

Specific conductance and pH were chosen for monitoring the inorganic constituents because they satisfy virtually every requirement for being acceptable test procedures and there are no alternative inorganic indicators which can provide equivalent informational value. pH affects the solubility and mobility of many of the toxic constituents of waste, and determines the rate and outcome of many of the chemical reactions the pollutant will undergo.

Specific conductance on the other hand is a numerical expression of the summation of contributions from all ions present in a solution. Since conductance is an additive property, it is useful as an indicator parameter because it can effectively determine all ions simultaneously. While pH and specific conductance are somewhat redundant, their relative change is informative.

TOC was chosen as an indicator parameter for organics because of its widespread use, acceptability as an effective test procedure, and general applicability to all types of organic contamination. It is one of the few parameters that provides a broad description of the organic content of water and is replacing chemical oxygen demand in ground-water analysis. TOC provides a more direct expression of organic content than COD, is more sensitive, and is a less difficult procedure.

TOX was selected to measure only those organic compounds containing halogens. Despite the somewhat more limited use of TOX, it is included among the four indicators in view of the relatively large amount of hazardous wastes which may contain halogenated hydrocarbons and the higher degree of toxicity usually associated with these compounds. The TOC test alone will not reliably detect the minor TOC fluctuations due to significant levels of halogenated hydrocarbon and the TOX test alone will not provide the broad range of organic coverage necessary.

In unusual situations where these four indicators are inappropriate for detecting discharges due to waste composition, the site geochemical characteristics or other circumstances, owners or operators are encouraged to notify the Agency of the details (see 47 FR 1254, Jan. 11, 1982). Otherwise, procedures for the alternate system (§265.90(d)) may be followed.

Owners or operators should be prepared for the shortest possible turnaround between the detection of significant ground-water effects and assessment plan development. It is expected that the detection phase monitoring will provide some specificity regarding the avenue of release and constituents of concern. The actual assessment plan will then be able to focus on a narrow spectrum of possible releases.

Section 265.93(d)(2,3) [specific plan for ground-water quality assessment] states:

> (2) The owner or operator must develop and submit to the Regional Administrator a specific plan, ... certified by a qualified geologist or geotechnical engineer, for a ground-water quality assessment program at the facility.
>
> (3) The plan to be submitted under §265.90(d)(1) or paragraph (d)(2) of this Section must specify:
>
> (i) The number, location, and depth of wells;
>
> (ii) Sampling and analytical methods for those hazardous wastes or hazardous waste constituents in the facility;
>
> (iii) Evaluation procedures, including any use of previously-gathered ground-water quality information; and
>
> (iv) A schedule of implementation.

The assessment plan should specify a phased program, probably commencing with analysis of a full suite of parameters from existing wells focusing on the characteristics of the wastes received at the facility. In the phased assessment program, data collection, analysis and evaluation will be pursued iteratively. For instance, the plan may indicate that earth resistivity surveys be conducted over a period of three months, that the surveys be analyzed, and that the information be evaluated so as to determine an appropriate well drilling or other hardware emplacement scheme for subsequent months.

Well drilling, sampling and analysis should also be staged so that a first round will be evaluated before decisions are made regarding subsequent rounds of drilling. There is no requirement that the plan first submitted after the notification will be a sophisticated and rigid program of events leading towards or producing the assessment. Rather, this detailed plan may need to incorporate some flexibility so that unexpected changes in plume configuration can be addressed.

Section 265.93(d)(5) [assessment and report] states:

> (5) The owner or operator must make his first determination under paragraph (d)(4) of this Section as soon as technically feasible, and within 15 days after that determination, submit to the Regional Administrator a written report containing an assessment of the ground-water quality.

The Agency recommends considering a decision-tree format for assessment plans with notification of incremental determinations rather than one-time assessments. Owners and operators, in consultation with the certifying professional, should determine when sufficient reportable information is accumulated to constitute the "first determination." The first determination should include the following information:

1. An estimate of the location and depth of the area of highest concentrations.
2. A sample of downgradient ground water which is beyond the limits of contamination, and an estimated location of the "front" of contamination.
3. A list of any hazardous waste constituents present in the ground water.

Since collection and evaluation of this information may require an extended study period, the Agency specifies a timely submittal of the first assessment report. Subsequent annual submission by March 1 of each year is required thereafter. Assessments, reporting and the required determinations must be completed in the shortest time practicable. As the required determinations are being submitted, each report should demonstrate that the assessment continues to satisfy the requirement for system capability. Necessary alterations should be submitted for Agency review.

Section 265.93(d)(7) states:

> (7) If the owner or operator determines that hazardous waste or hazardous waste constituents from the facility have entered the ground water, then he:
>
> (i) Must continue to make the determinations required under paragraph (d)(4) of this Section on a quarterly basis until final closure of the facility, if the ground-water quality assessment plan was implemented prior to final closure of the facility,... or

(ii) May cease to make the determinations required under paragraph (d)(4) of this Section, if the ground-water quality assessment plan was implemented during the post-closure care period.

Owners or operators should recognize that Part 265 provides no absolute ground-water standard for evaluation of a facility. Determinations as to the acceptability of any observed discharges will be judgmental. These judgments may be made after considering input from the owner or operator, adjacent land owners, state and local officials, and other interests. The objective of Part 265, Subpart F, is the determination of the facility's effect on ground water, not to determine compliance with a standard. Data shall be collected and analyses shall be performed in accordance with the regulations. Subsequent evaluations may lead to any of several options such as imminent hazard actions under RCRA Section 7003, further analysis under RCRA Section 3013, calling up Part B or conclusions that continued operation is appropriate without changes.

1.3 Program Implementation

During interim status, the Agency expects only to loosely identify the format for onsite ground-water monitoring records. The content and format of reports to EPA will be specified in more detail. At several points in the regulations, program contents are specified or implied. These are as follows:

(1) Detection system waiver demonstrations.

(2) A description of the alternate ground-water monitoring system (when the owner or operator decides to use an alternate system).

(3) The geologist or geotechnical engineer's description of the detection monitoring system design which demonstrates its capability. It should contain a description of the basis for selection of sampling point locations (i.e., gradient and flow path).

(4) Descriptions of well casing, screening, filter packing, annular sealing, and well logs.

(5) The ground-water sampling and analysis plan.

(6) The records of the analysis required in the detection monitoring program. The records should contain all determinations of change in the four indicator parameters whether confirmed by the lab error process or not.

(7) Background concentrations, and determinations of the need for change, and the history, including ground-water surface elevation analyses of §265.93(f).

(8) The plan for the assessment program.

(9) The written assessment report.

(10) Reports of quarterly assessment until final closure.

These components need not be separately addressed in individual documents. The format and manner of expression of program documentation is entirely up to the owner or operator for the implied requirements and for the portions which are to be maintained on site. However, Agency inspectors will be instructed to review the demonstration of each, so they should be readily identifiable.

The assessment plan must address the techniques for determining the presence, the rate of migration, the extent of migration and the concentrations of the hazardous waste constituents. Since rate of migration may vary for different contaminants, and it is a dynamic factor which requires considerable observation time, its determination may constitute the most extensive portion of the plan. Determination of extent of contaminant migration is largely site and facility specific, since it will depend upon the limits of sensitivity for the parameters of concern, their background levels, and their seasonal fluctuations. The least involved of the three portions of the plan may be the determination of contaminant concentrations. Having established rate and extent of migration, concentration isopleth mapping will often be relatively straightforward.

The initial level of detail of the plan depends upon the amount of information upon which the decision to prepare the plan has been based. If the owner or operator has rather detailed information upon which he bases his assumption that hazardous waste or their constituents have reached the ground water, or if the detection program which displayed the statistically significant change is relatively sophisticated, highly detailed plans should be expected. When the determination or assumption is based upon scant information, the initial level of detail of the plan may be somewhat less.

Assessment plans are different from compliance or corrective action programs in Part 264 in several respects, but, as with other aspects of interim status requirements, the product of an assessment will be an essential component of the permit application. For this reason, owners and operators who are or may be considering Part B submissions should describe in the assessment plan the relationship between the product of the assessment and any necessary steps for a permit.

1.3.1 Complying with the Regulation: How much is enough?

The monitoring requirements as promulgated were designed to be self-activating. EPA's experience in implementing the Clean Water Act with its numerous permit actions was part of the basis for Congress' decision to provide an interim status period before existing hazardous waste facilities would be issued RCRA permits. In order to achieve the smoothest transition, the Agency has prescribed procedures in which owners or operators of land disposal facilities would proceed automatically, where required, from one level of monitoring to the next without waiting for interaction with the Agency. The Agency has prescribed a sequence of steps leading to a ground-water quality assessment which must be automatically followed in the case of Agency silence. However, it should not be inferred that communication with EPA is being discouraged. On the contrary, the Agency's willingness to participate in ground-water quality assessments is expressed throughout this manual. Further, the Part 265 regulations require owners or operators to send notifications and reports to EPA.

This regulatory approach places a large measure of trust and confidence in the owner or operator. Owners or operators will design, install, and operate their monitoring systems, pending review during EPA inspection and review during the permit process. The question "How much is enough?" will be entirely site-specific, but in general, owners or operators should ensure that convincing evidence is established for each assumption and for demonstrating the basic capability of the system to produce samples representative of background and potentially impacted ground water. Examples of such demonstrations will be presented in this manual, but the reader should bear in mind that "enough" is a subjective determination, both for the questions of "how much" monitoring is necessary to detect ground water contamination and "how much" demonstration is required to convince the Agency of that capability.

The requirements for fulfilling the detection program are minimal and are specifically designed not to be burdensome. The objective of these requirements is to produce information for differentiating between facilities which are significantly affecting ground-water quality and those which are not. The detection system is cost effective and can positively identify those facilities with gross impacts, yet it is not particularly conservative (i.e., it minimizes propensity to err on the side of finding false positives).

Thus for the first-level objective, a simple detection system will suffice in a vast majority of cases. Only in the most unusual cases, such as facilities located on a tidally influenced aquifer, or those located along a ground-water divide, would the detection monitoring system need to be very sophisticated. Demonstration that the system is adequate could consist of cursory on-site geophysical confirmation of the continuity of regional characteristics.

The key word in the Subpart F regulations is capable. The owner or operator must install and implement a ground-water monitoring system capable of determining the facility's impact; it must be capable of yielding representative ground-water samples for analyses. The number, locations, and depths of the detection monitoring wells must be such that the system is capable of the prompt detection of any statistically significant differences in the four indicator parameters. Separate monitoring systems for each facility component are not required provided that the emplaced wells are capable of detecting any discharge from the waste management area.

At each description of the detection monitoring program in the regulations, the Agency has chosen performance oriented criteria to describe a sufficient system. Since it will be a very unusual monitoring situation in which fewer downgradient wells would insure system capability, the Agency has established in the regulations that the minimum system will consist of at least three wells downgradient. This is not intended, however, to be a suggestion or a guideline concerning the normal or typical monitoring system. Rather, it is the minimum acceptable, and the norm may be six, ten, or even more. It is not uncommon for monitoring system designers to employ multiple dozens of sampling points in detection monitoring.

The critical component in determining adequacy is the breadth or scope. Discharges to the ground water may originate in a variety of ways. Overtopping, spills, or liner rupture at surface impoundments, surreptious disposal of wastes incompatible with liners, equipment operator error during liner emplacement, or liner puncture by bulky objects in a landfill, are some of the obvious points of origin of discharges to ground water. Upon discharge which could be a one-time event, a repetitive or recurrent event, or a continuous seep, the discharge plume in the unsaturated zone could form a narrow ribbon or quite a large conical shape with significant lateral dimensions. Entry at the water table could be continuous, pulsing in sync with the original discharge, or transported by pulses of infiltration. It may behave as a point source or as a widely dispersed areal source. The discharge could consist of homogeneous constituents representing the full range of waste received by the facility, or it could consist of a unique fraction of the facility wastes. Even that fraction might be homogeneous or it might be widely varying. Plume bifurcation may result when oily or aromatic wastes tend to float on the surface of the water table while higher density fractions tend to form deeper plume configurations. Unless the plan fully considers potential as well as actual pathways, the occurrence of an unforeseen event could have a negative influence on the ability to effectively implement early corrective actions.

Assessment plans are required to be prepared professionally (i.e., by a geologist or geotechnical engineer). These professionals should pose an exhaustive list of possible release mechanisms in the initial design process of the plan. Anticipated viscosities and densities of the leachate and temperature differentials with the ground water should be coupled with actual and likely hydrologic flow paths at the site (including the prospect of geophysical anomalies); and each of the potential flow paths must be individually assessed regarding its likelihood of occurrence.

The Agency does not expect to establish hard and fast criteria to determine whether or not a particular flow path must be intercepted by a sampling point. Rather, the owner or operator must use judgment in establishing his sampling point array. He should take advantage of the fact that some of the flow paths may be redundant in that no leachate would travel one without having first appeared in the other. However, he must be capable of providing an EPA inspector with a convincing demonstration that any discharge from a facility would be detected by the system.

The regulations require determination of the water level, before flushing and sampling, in each well at each sample-taking event. These measurements should be used to compute the water table gradient (direction and slope) in order to demonstrate that the system continues to be located appropriately. Changes in the water table gradient should be assessed for their impact on the flow path probability; "how much demonstration" is therefore not answered by a once-and-for-all assessment. The system capability demonstration requires continuous updating.

The information achievable from the basic detection program, without waiver or alternate, is limited. Information from a waiver demonstration will be definitive regarding the potential for leachate to enter ground water and similarly, information from an alternate program will be more definitive than from the basic program. The objective of the basic program is basically to determine which land disposal facilities require in-depth assessment of ground-water impacts.

1.3.2 Interaction with the Agency

The Agency intends to be cooperative and interactive with owners or operators regarding interim status monitoring. However, owners or operators should bear in mind that information generated by the assessment program may, in certain instances, be used as evidence for enforcement purposes and that chain of custody requirements do apply. The assessment program is not designed in and of itself to provide sufficient evidence to support enforcement actions; rather, the program may be used in making the threshold determination of whether further investigation is warranted. If a disagreement persists and the enforcement proceedings prove necessary, the collection of additional information by the owner or operator will usually be necessary. It is the Agency's sincere hope that assessments will be conducted in a cooperative non-adversarial manner and that the regulatory staff may actively participate in review of assessment plans during drafting.

The Agency's role during interim status must be a limited one, advising only, with no approval implied. The product of an assessment will be the basis for negotiating alterations to the design or operating procedures at the facility; it will be a basis for discussions regarding the acceptability of the discharge, the longevity of the site, or the usefulness of a public hearing concerning the situation. To serve these purposes best, it behooves both the Agency and the owner or operator to assure the thoroughness of the investigation, and the Agency may require modification of inadequate plans. Upon completion of the assessment, owners or operators may be required to predict the fate and effects of a continued release of contaminants or of controlling the release by facility modification, removal of wastes, or hydrogeologic modification. This could be done pursuant to RCRA Section 3013 or in anticipation of an imminent hazard or enforcement action if necessary, and it will certainly be an issue during permit application review.

Since owners or operators of facilities which are assumed to have affected ground-water quality have been afforded the opportunity to commence directly with the assessment program, the detection program was designed with an assumption that the facility has not affected ground water. The first reaction to indications that an impact has been detected will be to double check the data. The regulations build in one double check against human error. The Agency suggests as a second safeguard against false positives that the assessment plan should prescribe analyses of waste-specific parameters from existing wells. Special attention should be paid to constituents known to be absent from the facility in order to determine whether other sources are causing or contributing to the situation. For instance, "fingerprint" analyses may form the first phase of the assessment program. If the fingerprint does not match, the owner or operator should return to a monitoring program whose objective is detection. If the fingerprint does match, the assessment plan may still emphasize confirmation of source or the portions due to various sources.

Owners or operators are encouraged to maintain informal communication with the Agency in addition to the required formal reporting. The Agency will place a high priority on responding to requests for assistance from owners or operators during development and implementation of assessment program plans. Owners or operators are advised that failure to comply with notification requirement will be a consideration in establishing facility inspection schedules and in calling Parts B.

As a general rule, monitoring programs must be carefully pre-planned so that each component of the system, each datum required, and each specified report will be meaningful and purposeful. Changing program dimensions and improved understanding of field conditions resulting from the experience of collecting data may be expected to affect the usefulness of certain items of data now being collected. Similarly, waivers and omissions could lessen the value of the overall picture by creating gaps in the data.

At the time of promulgation of the interim status standards, the Agency anticipated that the permit monitoring standards for land disposal facilities would be promulgated shortly thereafter. Subsequent difficulties in determining appropriate standards have caused delays resulting in unanticipated extension of the interim status period, as well as a greater opportunity for the Agency to interact with owners and operators during development of monitoring programs. Therefore, ground-water monitoring waivers and alternate programs, for instance, have been developed with the Regional Administrator advising (but not approving or disapproving in a formal sense) owners or operators of system sufficiency prior to its implementation. This is more particularly true for the assessment plan, but is applicable to the detection program as well.

The Agency will attempt to maintain consistency in the ground-water monitoring requirements throughout interim status. However, repeatedly identified problems, if and when they occur, will be periodically assessed with a view towards program improvement and revisions to the regulations. Whenever changes cannot be avoided, we will attempt to reduce any disruption which may result with due consideration for both owner or operator and program impacts.

2.0 Detection Program

2.1 Description

The ground-water monitoring detection program is intended to protect human health and the environment through the prompt detection of possible discharges of hazardous wastes or hazardous waste constituents into the ground water from a surface impoundment, landfill or land treatment facility. Owners or operators of such facilities are responsible for developing ground-water monitoring systems capable of detecting whether a facility is affecting ground-water quality in the uppermost aquifer underlying the facility. The purpose of this Section is to provide guidance and technical information to owners or operators in the development of a detection program meeting the requirements of the RCRA 40 CFR Part 265, Subpart F. Others interested in the content of this Section may include Agency staff, geologists involved in designing and installing a ground-water monitoring system and inspection personnel.

2.2 Ground-Water Monitoring Well Location

Ground-water monitoring wells must be capable of determining whether the facility is affecting ground water in the uppermost aquifer underlying the facility. The number and location (including surface position and depth) of wells must assure detection of ground-water quality changes (i.e., facility discharges) in the uppermost aquifer. Well location and number requirements represent only the minimum acceptable system components. Where the minimum requirements do not enable the owner or operator to meet the overall performance objective, he must determine where and how many additional wells are necessary. The regulations provide flexibility in adapting a system to site-specific hydrogeologic conditions. It is the responsibility of the owner or operator to develop the monitoring system necessary to accurately detect possible facility discharges.

Geologic factors, related chiefly to geologic formations and their water-bearing properties, and hydrologic factors which determine the movement of water in the formations should be known in some detail to properly design a detection system. The geologic framework includes lithology, texture, structure, mineralogy, and the distribution of the materials through which ground water flows. The hydraulic properties of the earth materials depend upon their origin and lithology, as well as the subsequent stresses to which the materials have been subjected.

The hydrogeology of the facility site heavily influences the monitoring well array. Elements of the hydrogeologic framework which should be considered include:

- the spatial location and configuration of the uppermost aquifer and its hydraulic properties (e.g., horizontal and vertical hydraulic conductivities, depth and location of ground-water surface, seasonal fluctuations of ground-water surface elevation); and

- hydraulic gradient.

2.2.1 Obtaining Hydrogeologic Information

Prior to initiating any field work, all existing geologic and hydrologic data should be collected, compiled and interpreted. Data that should be investigated include: geologic maps, cross sections, aerial photographs, and any water-well data including location, date drilled, depth, name of driller, water level and date, well completion methods, use of well, electric or radioactivity logs, or other geophysical data, formation samples, pumping test(s) and water-quality data. After compiling and thoroughly reviewing the collected data, the investigator can properly begin planning the monitoring well array needed.

The owner or operator should obtain as much regional and site-specific information as possible. In addition, the owner or operator is advised to consult more than one source for a particular type of information in order to verify the reliability of and supplement the data obtained. Table 2-1 lists possible sources of existing information.

The common field methods used for obtaining hydrogeologic information should be employed for on-site investigations including installation of boreholes, piezometers and/or water table wells; remote geophysical techniques such as electrical resistivity surveys may be used to augment direct methods. Descriptions and applicability of boreholes, piezometers, and water table wells are given below along with other direct and indirect field techniques (see also Section 3.3). It should be emphasized that some on-site investigation methods may be appropriate in one geologic setting but not in another. A combination of methods will likely be needed in most cases.

Table 2-1

Sources of Hydrogeologic Information

U.S. Geological Survey (USGS) [See Appendix B for specific contacts].

State Geological Surveys

U.S. Department of Agriculture, Soil Conservation Service

State Department of Agriculture

County Surveys

State Department of Environmental Protection

State Department of Natural/Water Resources

State Solid/Hazardous Waste Division

Clean Water Act "208" and other Regional Planning Authorities

County and Regional Water Supply Agencies and Companies (private water suppliers)

Related industry studies (mining, well drilling, quarrying, etc.)

Professional associations (GSA, NWWA, AGU) [1]

Local colleges and universities (Dept. of Geology, Earth Sciences Civil Engineering)

Other Federal/State Agencies (ACOE, NOAA)[2]

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[1] GSA - Geological Society of America
NWWA - National Water Well Association
AGU - American Geophysical Union

[2] ACOE - Army Corps of Engineers
NOAA - National Oceanic Atmospheric Administration

The evaluation of hydrogeological conditions at the site should be under the direction of a qualified geologist or geotechnical engineer.

Boreholes

Boreholes should be drilled on-site to obtain information (direct and indirect) on subsurface geology, including fluids present. The following purposes for drilling boreholes should be achieved:

- to verify results of surface geophysical surveys (e.g., electrical resistivity and electromagnetic conductivity; see Section 3.3);
- to locate aquifer flow zones (i.e., probable contaminant pathways);
- to determine the types, properties, and thicknesses of earth materials penetrated by obtaining formation samples or through use of indirect techniques (e.g., borehole geophysical logging; see Section 3.3);
- to enable collection of water samples through installation of monitoring wells;
- to define the extent of a contaminant plume (areally and at depth);
- to plot underground stratigraphy and structure by correlating data from different boreholes; and
- to enable in situ testing (e.g., pumping tests to determine aquifer coefficients and tracer tests to examine contaminant transport).

A boring plan should be prepared by the geologist or geotechnical engineer in charge of the investigation. The plan should include proposed locations and anticipated depths of boreholes and the type and frequency of formation sampling required. When to terminate boreholes and/or when additional boreholes are needed depends upon additional data needs and site-specific hydrogeologic factors. For example, a shallow bedrock surface of low hydraulic conductivity may indicate the depth limit for investigation of an area. All information obtained during boring should be recorded on standard boring logs.

Detailed discussion of standard boring procedures may be found in Hvorslev (1965), Acker (1974) and other standard references (e.g., ASTM, 1978). Table 2-2 shows how boreholes

Table 2-2

Methods Used to Identify Uppermost Aquifer and Hydraulic Gradient

Identify	Direct Methods	Data Obtained	Indirect Methods	Data Obtained
The Uppermost Aquifer	- boreholes	- stratigraphic column - thickness of formation - location of water-bearing zones - lithology, soil classification	- review of previously documented information	- any applicable data
			- geophysical logging	- aquifer thickness - hydraulic conductivity of strata - porosity - lithology
	- piezometers and water table wells	- ground-water surface elevations	- surface electrical resitivity and electromagnetic conductivity surveys	- aquifer thickness - hydraulic conductivity of strata - porosity - lithology
			- seismic surveys	- density differential hydraulic conductivity of strata lithology
			- records from existing wells	- historical ground-water surface elevations - saturated zone - lithology
Hydraulic Gradient	- piezometers and water table wells	- ground-water surface elevations		

and other direct and indirect methods are useful in identifying the uppermost aquifer. For further information on the purposes and methods of sampling subsurface solids, see Scalf, et al (1981, pp. 72-79). See also Section 3.3 for additional considerations concerning boreholes.

Piezometers and Water Table Wells

A piezometer is a narrow well (generally less than four inches) used for measuring ground-water surface elevations (i.e., heads). Care must be exercised in installing the casing to insure that accurate water level elevation measurements are obtained. Information for designing and installing piezometers is given by Fenn, et al (1977, pp. 86-88). Piezometers and/or water table wells should be used in determining the water surface elevation in the uppermost aquifer, seasonal fluctuations of this elevation and the hydraulic gradient. A minimum of three piezometers should be used to determine the hydraulic gradient. Additional piezometers will generally be needed since three will often be inadequate to determine the variations in ground-water flow at a specific site. Where appropriate, piezometers can also be used as monitoring wells, provided they meet all the specific requirements of monitoring wells in Sections 2.2 and 2.3.

Seismic Surveys

Seismic surveys are used to determine the depth to bedrock and the thickness of the materials overlying the bedrock. The refraction method of seismic exploration utilizes the principle that energy waves can be propagated through earth materials. The velocity of propagation is governed by the elastic properties of the earth materials through which the waves are traveling. To determine their velocity, these elastic waves can be timed from their initiation to arrival at a known distance from the energy source. With known velocities and distances, depths to the various geologic interfaces can be calculated. The seismic reflection method of geophysical surveying may also be used. This system, in which the energy wave is reflected from the different geologic horizons, can usually penetrate greater depths than the refraction method. For more refined interpretations, well data are correlated with the results of the seismic survey. Where well information is not available, evaluation of seismic data is based upon interpretation of the geologic environment and experience in geophysics. Data interpretation of a seismic survey requires a trained operator and an experienced geophysicist. The complexity of the data-reduction process generally requires the use of a computer. For further information on the use, advantages and limitations of this methodology, see Fenn, et al (1977, pp. 124-126).

2.2.2 How to Use Hydrogeologic Information in Planning the Monitoring System

Existing and new on-site investigation information should be used to deduce the configuration of the site-specific hydrogeolgic framework. This framework is the primary influence in determining the number, locations and depths of monitoring wells. Such information should be used to:

- prepare a site base map;
- characterize the hydrogeologic framework (including identifying the uppermost aquifer); and
- determine the hydraulic gradient.

Preparing a Site Base Map

In order to verify that the location requirements for upgradient and downgradient wells are being met, the Agency recommends that a site base map be prepared. The base map can be used extensively throughout the well location process to summarize and display information collected. In addition to its use for contour plots of the ground-water surface elevation, a base map should also be used in planning and excecuting the on-site investigation. The area to be covered by the base map should be selected to best represent the significant features at each facility. The base map should extend beyond the facility area to cover other areas that may be affected by facility discharge. USGS topographic quadrangles and aerial photographs may help in deciding how far to extend the base map.

Municipal tax maps available from Town Clerks at local Town/City Halls may provide useful information for a base map (e.g., facility boundary lines, rights-of-way, structures, pipelines).

The base map may be prepared, in part, from information from aerial photos (photogrammetry) yielding pertinent information on location of surface features. Departments of Transportation, Departments of Environmental Protection and County Planning Departments generally catalogue state or regional aerial photos. Agricultural, landscape design and other related academic departments at colleges and universities throughout the country also maintain aerial photographs. Federal offices that serve as repositories of aerial photographs for major regions in the country include:

- National Headquarters
  National Cartographic Information Center
  United States Geologic Survey
  507 National Center
  Reston, Virginia 22092
  (703) 860-6045.

- U.S. Department of Agriculture, ASCS
  Aerial Photography Field Office
  P.O. Box 30010
  Salt Lake City, Utah 84130
  (801) 524-5856; and

- Center for Cartographic and Architectural Archives
  Cartographic Archives Division
  National Archives and Record Service
  Washington, D.C. 20408
  (202) 523-3006.

An appropriate scale for a base map is one inch equal to not more than 200 feet (1:2400), unless other factors override. (NOTE: The USGS, in converting to metric representations, commonly employs a scale of 1:2500, which is also a useful scale.) Although available aerial photographs do not usually provide this level of detail (i.e., one inch equals 2,000 feet is a commonly available scale for aerial photographs), information obtained on land surface features and man-made structures is very useful in base map preparation.

Important features which should be located on the base map include:

- facility-related structures (e.g., buildings, roads, parking lots, existing wells, pipelines, bench marks, soil and water sampling areas, foundation test borings);

- potential contamination sources (e.g., impoundments, landfills, storage areas, septic tank and drain field locations);

- probable and existing background plumes from other sources;

- surface water drainage direction and discharge points (e.g., streams, ponds), drainage patterns and divides;

- withdrawals (e.g., wells, springs); and

- vegetation.

Underground structures which must be located and avoided when boring and installing monitoring wells should appear on the base map, especially if they can interfere with some types of geophysical investigations (e.g., electrical resistivity and electromagnetic conductivity).

Vertical and horizontal controls on the site are necessary in order to determine hydraulic gradients. Such controls should be based upon values established by the U.S. Geological Survey or the U.S. Coast and Geodetic Survey.

Characterizing the Hydrogeologic Framework

Data from existing sources and on-site investigations serve as the basis for determining monitoring well locations, numbers and depths most appropriate to a particular facility. At a minimum the owner or operator should:

- determine hydraulic properties of formations;
- record the seasonal fluctuations in the ground-water surface elevations to determine the hydraulic gradients, including flow directions; and
- identify the uppermost aquifer.

Determining Hydraulic Conductivities of Formations

Hydraulic conductivity (K) of a porous medium, or the volume of water that will move in a unit time under a unit hydraulic gradient through a unit area measured at right angles to the direction of flow (Lohman, et al, 1972), should be determined. Irregularities in ground-water flow pathways which result from variations in K of subsurface materials should be identified. Soils and sedimentary rocks occurring in alternating layers or zones of varying K should be identified if they strongly influence ground-water flow patterns. Because ground-water flow patterns and, therefore, K distributions are a major influence on the well-location process, it is important to establish the K values of formations underlying the facility. Methods for determining K values of subsurface material samples are discussed in Section 3.2.

The following hydrogeologic situations reflect how K values can be considered in planning the monitoring system.

Low Hydraulic Conductivity Layers and Stratification

Where a shallow layer of low K is a continuous barrier to the downward migration of water or liquids under a facility, it will be a major influence in determining the location and depth of the monitoring wells. Therefore, if boring indicates the presence of a shallow, low K layer, such as a clay bed, its horizontal extent, thickness and degree of continuity in the vicinity of the facility site should be determined.

Even within an apparently homogeneous formation zone or aquifer, considerable differences in grain size and sorting (i.e., stratification) can occur in horizontal layers and should be noted. The influence of stratification on the vertical component of ground-water flow is an important consideration in determining the most effective depth for monitoring. Hydraulic conductivity often tends to be considerably higher (often at least an order of magnitude) parallel to the stratification than across it. Stratification and other variations in K of an aquifer should be evaluated by comparing horizontal and vertical K values.

Sand and Gravel Aquifers

Ground-water flow in unconsolidated sand and gravel aquifers is primarily intergranular. Because of the more uniform nature of most sand and gravel aquifers, ground-water flow in these formations is somewhat more predictable than in other formation types (e.g., fractured bedrock aquifers).

Bedrock Aquifers

In contrast, most consolidated rocks have few intergranular openings for ground-water flow and on a microscopic scale have very low K values. Instead, ground-water flow in bedrock aquifers takes place mainly through secondary openings such as fractures and/or solution cavities. Owners or operators should fully identify areas in which this factor is important. Although regional flow patterns should be discerned, it is often very difficult to predict ground-water flow through a set of randomly oriented secondary openings on a site-specific scale (e.g., in the vicinity of a monitoring well). Thus, owners or operators of facilities located over bedrock aquifers should employ additional investigative techniques (e.g., tracer tests and pumping tests) to adequately determine likely ground-water flow pathways.

Determining Seasonal Fluctuations of Ground-Water Surface Elevation

Natural fluctuations of the ground-water surface elevation caused by seasonal variations in the hydrologic cycle (e.g., precipitation amount and intensity) should be recorded. Such fluctuations are important in determining the depth of monitoring, especially when monitoring near the top of the uppermost aquifer.

Historical ground-water surface elevation data for any wells in the vicinity of the facility should be obtained (e.g., from the USGS) for the most recent 10-year period. Hydrographs for these wells should be examined, especially for wells with the most continuous data for the 10-year period and best locations (i.e., nearest the facility and tapping the same aquifer). A typical hydrograph is shown in Figure 2-1. Each hydrograph summarizes data from one well so that seasonal trends in the elevations are evident. The seasonal range in ground-water surface elevation should then be identified and its impact should be considered during the well location process. Monitoring well locations should be demonstrated capable of providing water samples throughout the year.

Hydrographs should be constructed for data collected from piezometers or water table wells installed at the site. They should reflect whether the ground-water surface underlying the facility is being affected in any anomalous way that deviates from seasonal trends. In cases where activities such as localized pumping of water supply wells results in additional fluctuations in ground-water surface elevations, the effects of these activities must be considered in determining monitoring locations and depths.

Preparing Subsurface Cross Sections and Identifying the Uppermost Aquifer

Subsurface cross sections mapping vertical profiles under the facility site should be prepared if needed to visualize the flow system. Subsurface conditions and hydrogeologic factors such as lithology and geologic structure (e.g., soil or rock type and thickness), formation stratification or layering, secondary porosity and/or hydraulic conductivity, constitute the framework which controls the occurrence and movement of ground water. These factors should be considered in determining locations of monitoring wells. The construction of subsurface cross sections, using information from boring logs, geophysical surveys and background information, is useful for presenting and evaluating this data, especially for complex hydrogeological conditions. (See Figure 2-2 for an example of a cross section.)

Subsurface cross sections used in conjunction with a site base map add a third dimension to the facility hydrogeologic framework that will be useful in meeting monitoring well location requirements. At least two cross sections, preferably perpendicular to each other with one section aligned with the anticipated ground-water flow direction, are recommended.

Figure 2-1
Typical Hydrograph

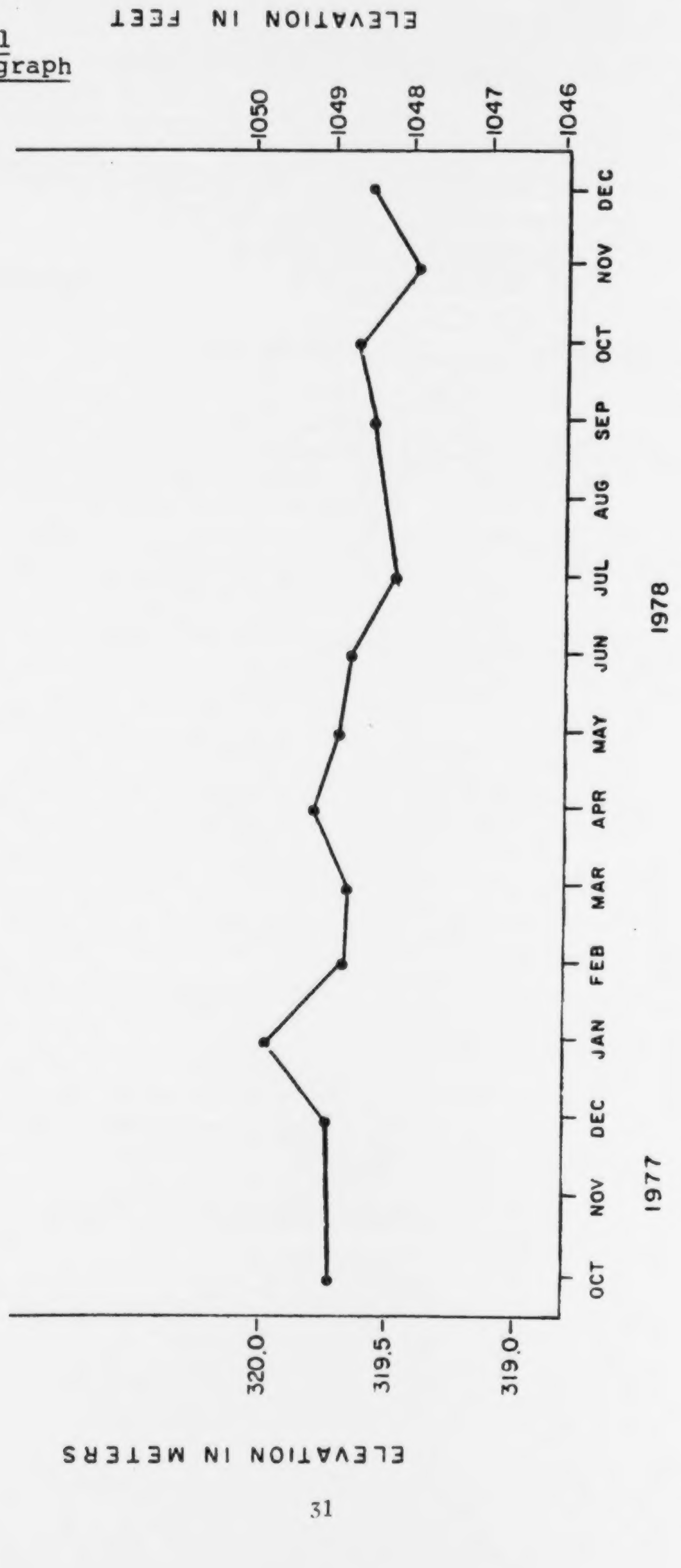
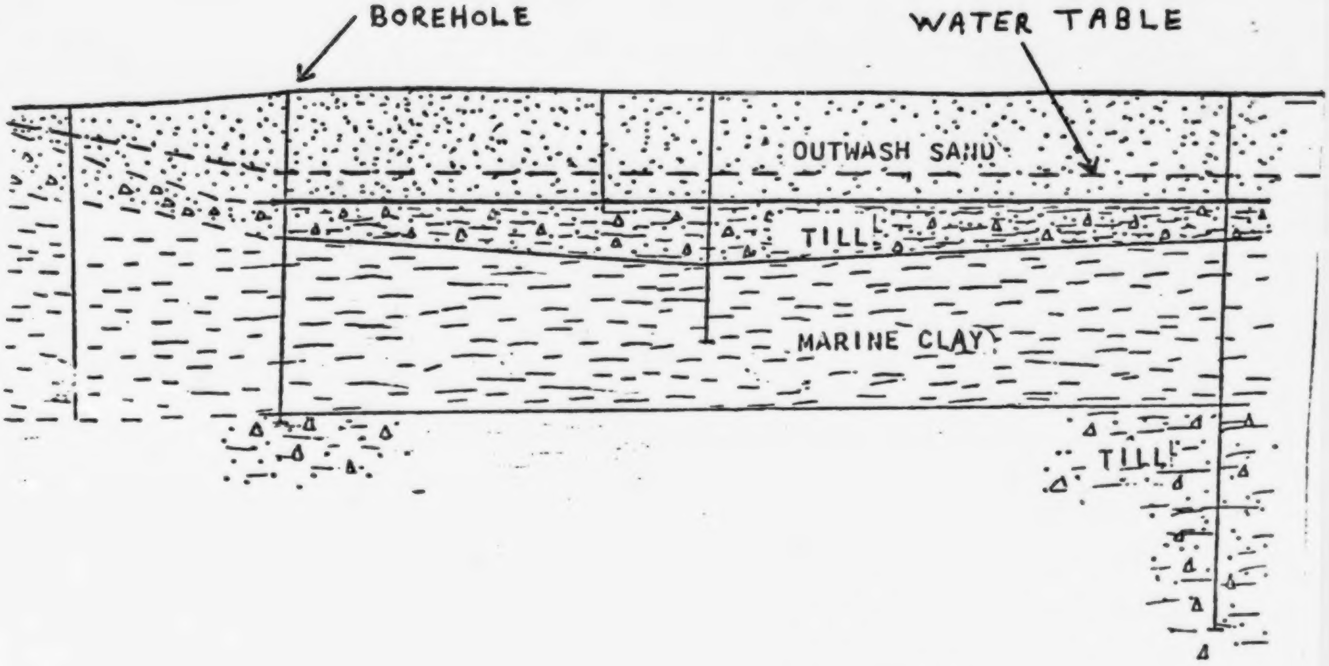


Figure 2-2
Hydrogeologic Cross Section



BOREHOLE
WATER TABLE
OUTWASH SAND
TILL
MARINE CLAY
TILL

horozontal scale 1"=260'
vertical scale 1"=10'

Using the prepared subsurface cross sections and water surface elevation information, the depth to the ground-water surface can be determined for purposes of selecting monitoring depths. Subsurface cross sections should be continually updated or improved as new data is obtained. Where complex subsurface conditions are indicated, additional boreholes, etc. should be drilled for verification.

Determining Hydraulic Gradient

Water from the surface percolates vertically downward through the unsaturated zone to the saturated zone where it then flows in a more lateral direction, from areas of higher to lower hydraulic head. The hydraulic gradient within the uppermost aquifer must be determined in order to effectively locate monitoring wells (see also Section 3.2.). The hydraulic gradient is the change in head per unit of distance in the direction of the maximum rate of decrease in head (Lohmann, et al; 1972). If sufficient data is available on the ground-water elevations, a water level contour map can be constructed, and from this hydraulic gradients should be determined through construction of a flow net (see Figure 2-3).

The minimum information needed from the on-site investigation is the ground-water surface elevations (i.e., hydraulic heads) from three piezometers. This data should be collected concurrently (preferably during the same day) from all three (or more) piezometers. Because these data points are extrapolated in constructing the ground-water surface contour map, the more data points collected (or water level measurements taken), the more accurate the flow net will be; (hence, a more comprehensive determination of hydraulic gradients).

A flow net can be constructed in the following manner:

- The ground-water surface elevation at each well is plotted on a base map of the facility area. These water level elevations are then used to extrapolate equipotentials (or head contour lines) which describe the shape and slope of the water table (see Figure 2-3).

- When assuming isotropic, homogeneous aquifer conditions, the ground-water flow direction is defined on the flow net by drawing ground-water flow lines that are perpendicular to the equipotential lines.

- The hydraulic gradient is determined by using two points on the map, located on different equipotential lines (e.g., one upgradient and one downgradient of the facility), and aligned on one ground-water flowline. Divide the difference in ground-water surface elevation

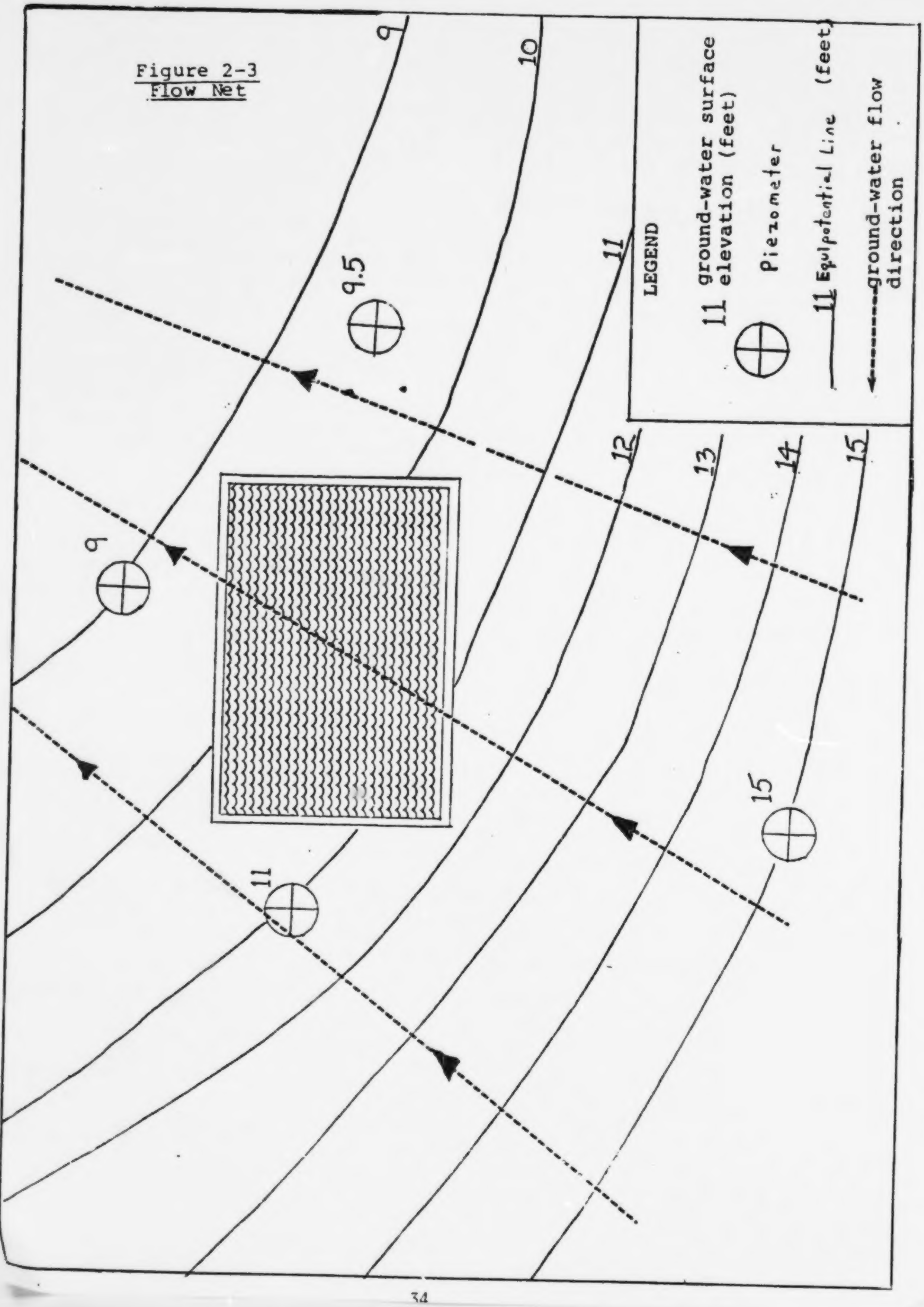


Figure 2-3
Flow Net

9
10
11
12
13
14
15
9.5
9
11
15
LEGEND
11 ground-water surface elevation (feet)
Piezometer
11 Equipotential Line (feet)
ground-water flow direction

(i.e., difference in heads) between the two points by their distance apart according to the scale of the map.

2.2.3 Location and Number of Monitoring Wells

Ground-water monitoring wells must be located so that a contaminant discharge from the facility into the uppermost aquifer is detected promptly. Section 265.91(a) requires a minimum of four ground-water monitoring wells with at least one well located hydraulically upgradient and at least three wells located hydraulically downgradient from the waste management area. The Agency has determined that four wells are the least number of wells needed to detect a contaminant discharge under the simplest of conditions. Since many sites have complex facility design and hydrogeology, owners or oprators of these facilities will likely need to install more than four wells in order to meet the objective of promptly detecting changes in ground-water quality caused by a facility. Factors to be considered in determining both the number and location of the wells include:

- ground-water flow patterns; and
- the size, orientation, and boundaries of the facility and the waste management area.

Section 265.91(a) requires that the upgradient ground-water monitoring well(s) yield ground water samples that are: representative of background ground-water quality in the uppermost aquifer near the facility and not affected by the facility. The distance upgradient from the waste management area that a ground-water monitoring well should be located is dependent upon hydrogeological factors (e.g., mounding effects). Downgradient wells should be located in close proximity to the waste management area boundary (without creating a conduit for potential contaminants to enter the ground water) to enable the prompt detection of any facility discharge.

Ground-water Flow Patterns

The pattern and direction(s) of ground-water flow are essential factors for determining the number of wells needed and their placement in relation to the waste management area. Flow patterns caused by various hydrogeologic conditions are used to determine flow pathways that contaminants may travel if they enter the ground-water system.

Downgradient wells should be installed in the uppermost aquifer in the direction of flow along flow pathways most likely to transport contaminants. These pathways should be located from data gained from existing information and on-site investigation. Upgradient wells should be placed within ground-water flow pathways that extend beneath the facility. Examples of well placement for common ground-water flow patterns are given in Figure 2-4.

Examples of Ground-Water Flow Patterns

The following examples of ground-water flow patterns that may influence the locations and number of monitoring wells are ideal and simplified and may only superficially reflect actual site conditions; but the level of detail required may often be little more than shown. (For further information on flow patterns and monitoring methods, see Fenn, et al, 1977, Chapter 2.)

These examples are designed to accompany Figure 2-4; and will define each flow pattern and discuss well location in relation to such patterns.

Parallel

Such a flow pattern results when equipotential lines are parallel; ground water is uniformly flowing in one direction. The aquifer materials tend to be homogeneous; hydraulic properties tend to be uniform with little restriction or segregation of ground-water flow into discrete pathways. Contamination spread in this flow pattern tends to be uniform and is more predictable than many other flow situations. Well placement with even spacing is generally suggested in such cases.

Converging

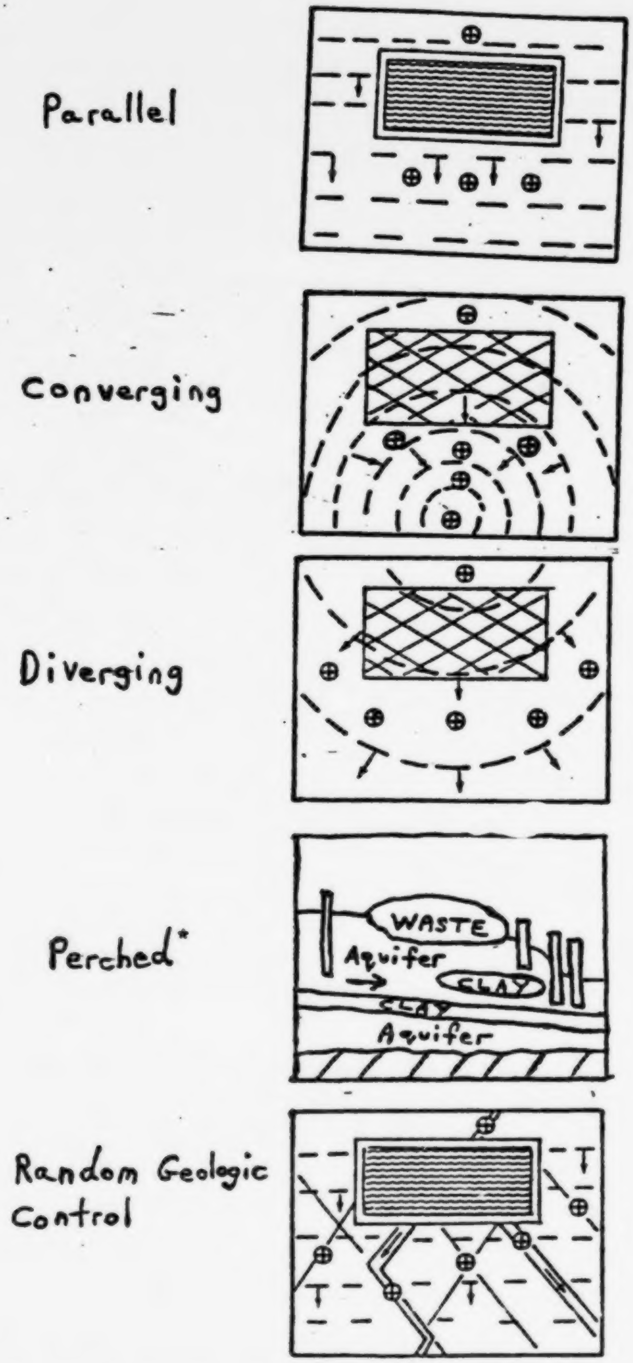
A converging pattern results when flow lines are directed toward a centralized point (e.g., a cone-shaped topographic depression).

A water supply well drawing water from the uppermost aquifer underlying the facility can also create a converging flow pattern in the local ground-water surface. Because water is converging towards the depression, mobile contaminants will likely flow toward that depression. The monitoring system in such cases should reflect these flow conditions, but must be re-evaluated as pumping conditions change.

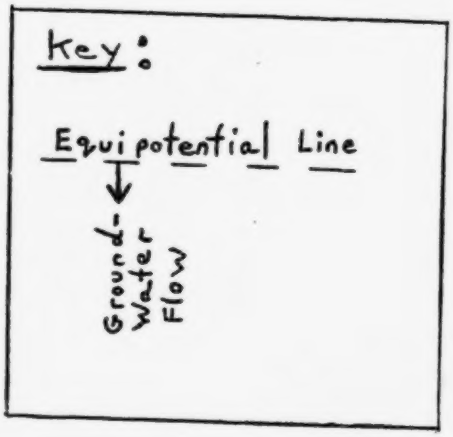
Diverging

Percolation into a hilltop or curved ridge may cause ground water to flow radially outward, resulting in a diverging ground-water flow pattern. In such cases, owners or operators

Figure 2-4
Ground-water Flow Patterns


Parallel
Converging
Diverging
Perched*
WASTE
Aquifer
CLAY
CLAY
Aquifer
Random Geologic Control

*Section view; all other diagrams are map views.


Key:
Equipotential Line
Ground-Water Flow

will be expected to define the effect on location of background wells. In general, downgradient wells should be placed in a pattern radiating outward from the recharge area. A large number of wells may be necessary to adequately cover diverging ground-water flow.

Perched

Determination of the uppermost aquifer may be difficult because of the existence of perched water zones which may or may not be continuous beneath the entire facility. Upgradient and downgradient wells at such facilities should be installed at depths which enable the detection of a facility discharge in the appropriate flow zones. That is, to obtain suitable samples from upgradient and downgradient wells the samples must be extracted from wells which intercept ground-water within the same flow system. Monitoring wells may be installed in perched aquifers, especially when the perch is continuous beneath the entire facility.

Random Geologic Control

Random flow patterns make monitoring well location a difficult process. Such flow patterns may be due to:

- fractured bedrock, characterized by a complex irregular fracture system through which water may migrate;

- solution cavities which often develop in fractures in carbonate rock and can direct ground-water flow along upredictable pathways; and

- discontinuous subsurface geologic conditions which may be caused by changes of hydraulic conductivity within the aquifer, such as is characteristic of alluvial deposits.

Locating wells in complex flow patterns presents particular difficulty. Flow patterns/migration pathways should be identified using both direct and indirect techniques of subsurface investigation (see Section 3.3). Numerous wells may be needed to detect migration from the many possible pathways presented by particularly complex hydrogeological settings.

Orientation and Boundaries of Facility and Waste Managment Area

The size of both single and multi-component facilities must be considered in determining the number and location of monitoring wells. A large facility may increase the potential to release contaminants through a greater number of possible migration pathways. For example, a large facility may extend over more than one drainage basin, with surface and ground water flowing in several and often opposite directions. The likely migration pathways in each basin should be monitored.

Under uniform ground-water flow conditions (e.g., sand and gravel aquifer with uniform gradient) and with no specific (e.g., structurally controlled) migration pathways identified, the spacing between monitoring wells should be close enough (e.g., not greater than every 250 feet of waste area frontage) so as to detect localized discharges. Even at this spacing, a localized facility discharge could go undetected as shown in Figure 2-5. Also, additional monitoring wells should be installed under unknown and/or complex subsurface conditions (e.g., when the ground-water flow direction or likely pathways are not adequately determined; or when geologic conditions such as bedrock fracturing or solution cavities create random flow patterns).

At multi-component facilities, where the waste management area is large and encompasses several waste management components, more than three downgradient wells will likely be necessary to detect contamination from any component.

When a waste management area is many times longer in one dimension than in another, its orientation with respect to the direction of ground-water flow can be a significant factor in determining the number and location of monitoring wells needed as shown in the example facilities in Figure 2-6.

Wells should be strategically located on the site so as to detect potential hazardous waste migration within the uppermost aquifer. Wells must be located and constructed in such a manner that they will not serve as a conduit for surface contamination to reach ground water. Special provisions should be taken for areas of the site where ground surfaces are contaminated (e.g., from surface spills, etc.) Protective provisions should be initiated during drilling and casing installation phases to help prevent interference with sample chemistry, contamination of the aquifer and exposure of workers to contaminants.

2.2.4 Monitoring Well Depth

No specific (i.e., numerical) well depths are specified by the regulations. However, the chosen depths of monitoring wells must satisfy the general performance standards stated in §§265.91(a) and (c). For upgradient wells, depths must be sufficient to yield ground-water samples from appropriate aquifer flow zones that are representative of background ground-water quality in the uppermost aquifer near the facility

Figure 2-5
Localized Discharge from a Facility

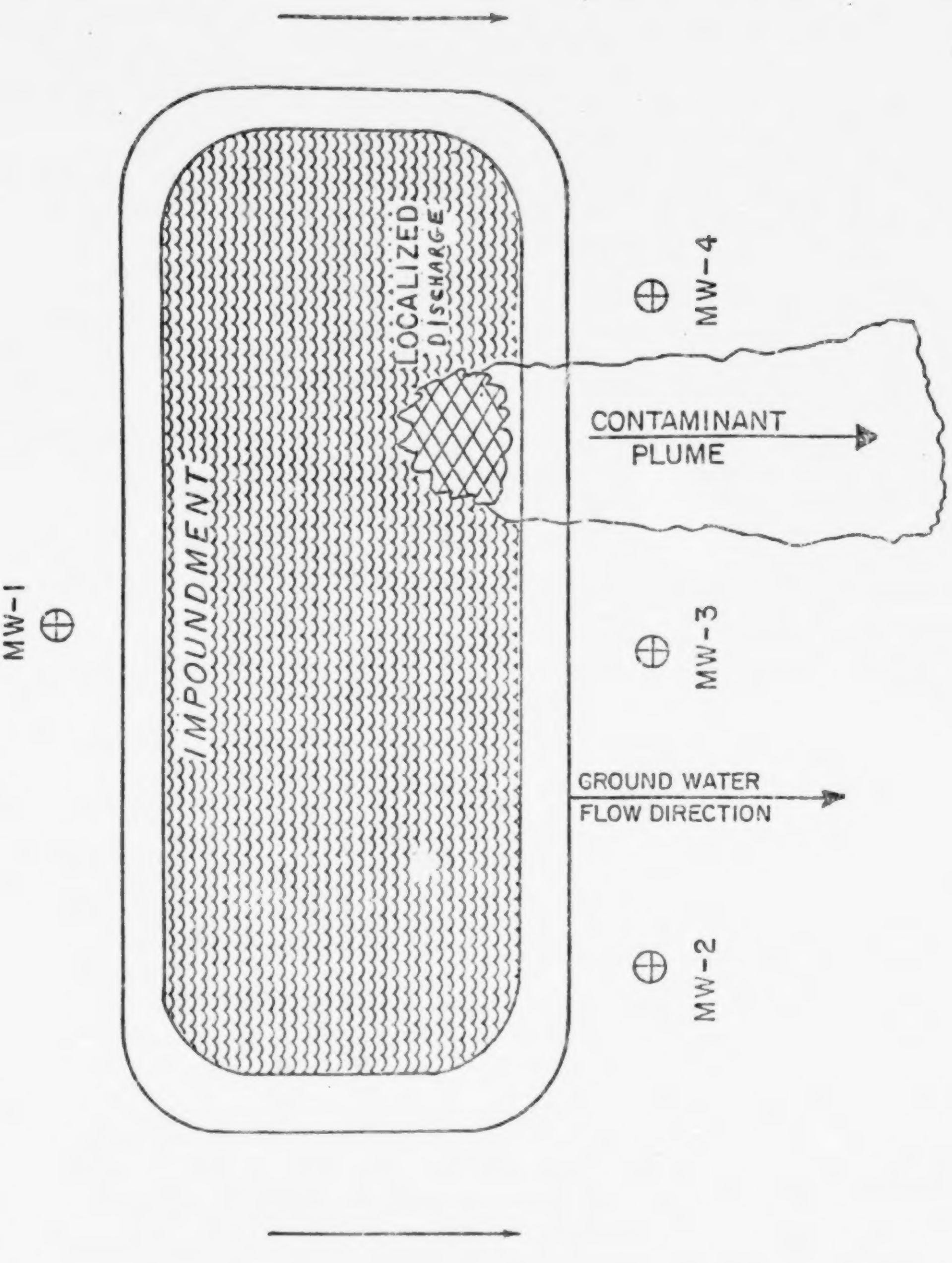
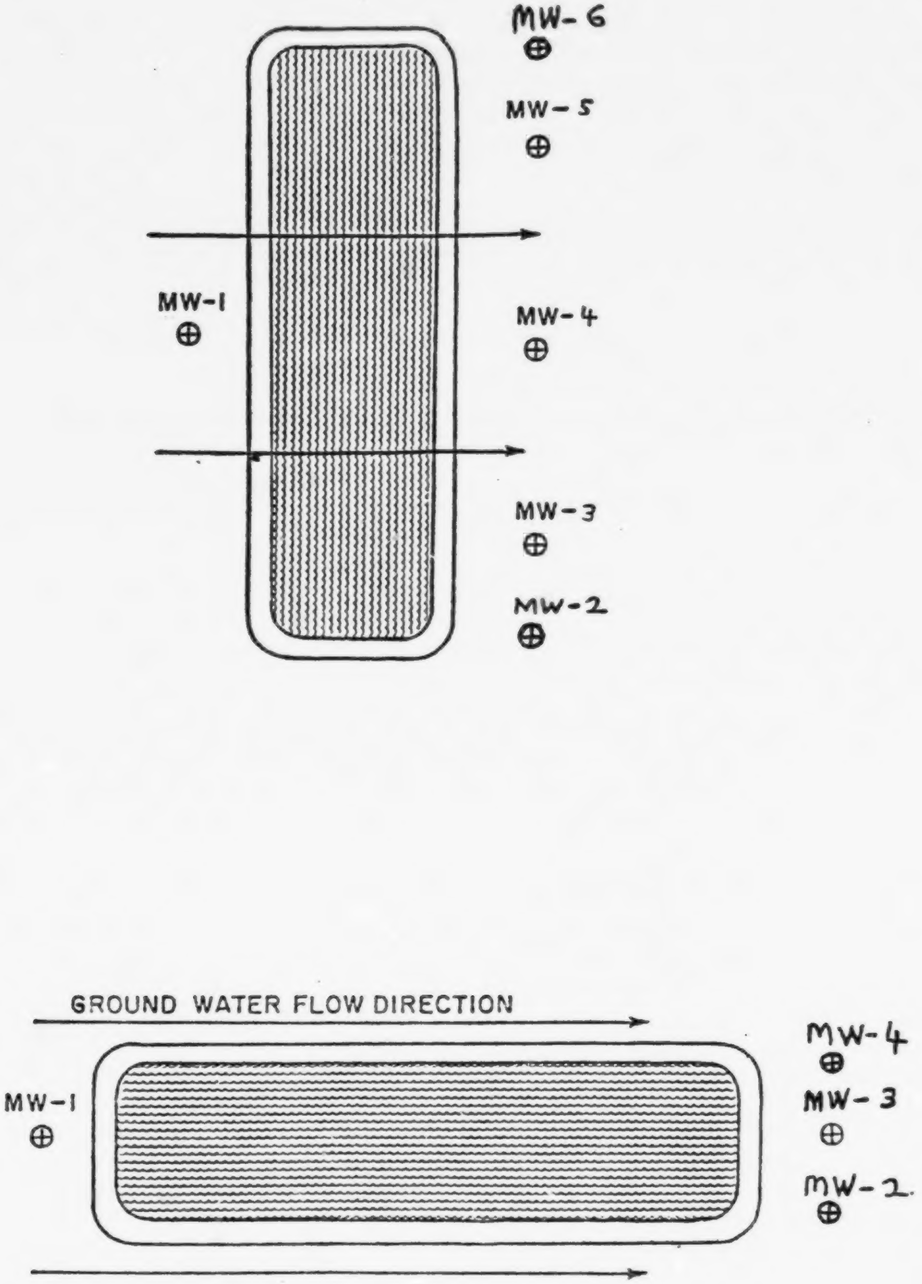

IMPOUNDMENT
LOCALIZED DISCHARGE
CONTAMINANT PLUME
MW-1
MW-2
MW-3
MW-4
GROUND WATER FLOW DIRECTION

Figure 2-6
Significance of Facility
Orientation


MW-6
MW-5
MW-1
MW-4
MW-3
MW-2
GROUND WATER FLOW DIRECTION
MW-4
MW-1
MW-3
MW-2

and not affected by the facility. The depth of downgradient wells must ensure that they enable the prompt detection of any significant amounts of hazardous waste or hazardous waste constituents that migrate from the waste management area to the uppermost aquifer (i.e., they must enable sample collection at depths where contaminants would likely be found).

Appropriate well depths and intake depths must be determined on a site-specific basis. Factors which influence well depth include:

- ground-water surface elevation (e.g., seasonal water table fluctuations);

- any anomalous ground-water surface elevation fluctuations (e.g., localized pumping effects); and

- contaminant behavior in the aquifer (e.g., density effects).

Ground-water surface elevations at various locations at the facility site will have been measured in piezometers and/or water table wells during the on-site investigations. This information should be considered with regard to seasonal fluctuations in ground-water surface elevations and any observed anomalous water table fluctuations to define the minimum depth necessary for each well. The chosen depth should account for any variation of the ground-water surface caused by seasonal or man-made fluctuations.

It may be difficult to determine appropriate well depths for an aquifer where the ground-water surface configuration is being artifically altered (e.g., by localized water supply well pumping or mine dewatering). The owner or operator may need to seek additional information (e.g., from the well owner or mine owner) in order to define the trends of the ground-water surface elevation fluctuations. Minimum monitoring well intake depths should be determined in regard to the lowest expected ground-water surface elevation and provide an additional margin of safety for any unexpected seasonal fluctuations. In cases where anomalous effects are severe enough to alter the local ground-water flow patterns, owners or operators will have to periodically reassess well locations, number, and depths.

The positioning of the well intake (e.g., screened or perforated portion of the casing) and total depth of the well will depend upon both the saturated thickness of the aquifer and the anticipated contaminant behavior in the aquifer. For example, contaminants much denser than water would be expected to sink rather rapidly in an aquifer and then migrate laterally in the lower reaches of the aquifer; whereas, "buoyant" contaminants (e.g., lighter hydrocarbons) would be expected to migrate near the top of an aquifer. The well depth and position of the intake should correspond to the most likely depth of the contaminant plume within the aquifer.

In many cases, the precise behavior of a complex mixture of hazardous waste contaminants in the aquifer cannot be adequately defined. Under these circumstances, the monitoring well network should be designed to sample the uppermost aquifer at several depths or flow zones in a given area (see Figure 2-8 on well clusters). Single wells with multiple sampling points may also be employed (see Fenn, et al, 1977, pp. 97-98).

In aquifers where ground-water flow and contaminant migration through fractured rock or solution channels is "random", it is difficult to pinpoint appropriate monitoring well depths. Often, drilling by trial-and-error may be necessary to determine at what depth ground-water flow will be intercepted.

2.3 Design and Installation of Monitoring Wells

Regulatory objectives for monitoring wells, presented in §265.91(c), are to maintain the integrity of the monitoring well borehole, enable sampling at depths where appropriate aquifer flow zones exist, and to prevent contamination of samples and the ground water. Sound engineering design principles and installation procedures are essential to the performance and longevity of monitoring wells. In order to meet the objectives of the ground-water monitoring program, additional design features that are dictated by the uniqueness of an individual facility setting may need to be considered. For further information on construction of monitoring wells, see Scalf, et al (1981, pp. 17-42).

2.3.1 Design and Planning Factors

Major elements which must be addressed in well design are the casing (housing of the well) and the well intake. The casing should be demonstrated to be capable of adequate support. The intake design must provide for extraction of representative samples, minimize formation materials from entering the sample, and provide structural stability in unconsolidated earth materials. Appropriate well and filter pack materials selection must be carried out so that parameter analyses will be minimally affected.

Other planning factors which may affect the parameter analysis and should be considered include the drilling method, sealing, casing installation procedures, development method, and the intended sampling method. Factors related to casings and intakes are discussed below.

Casing Design

Casing design involves consideration of proper size (i.e., diameter) selection to allow for efficient sample collection (e.g., to provide access for sampling equipment); and selection of casing materials to ensure that sample analyses will be minimally influenced by interactions with the casing material (see well material selection discussion, later in this Section).

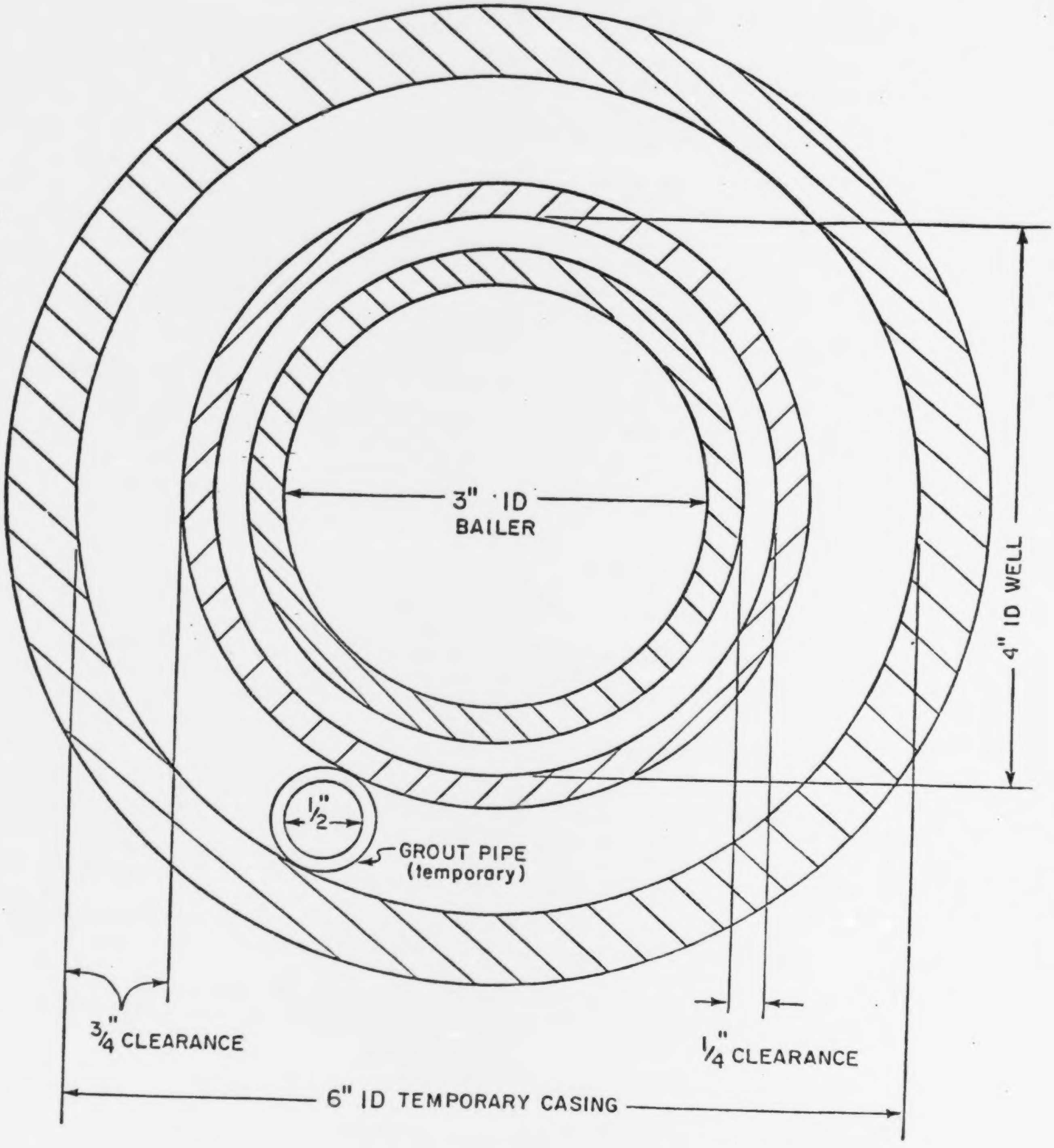
In order to assure that samples are representative of the ground water, contamination must be avoided during the sampling process. The casing diameter should be determined with regard to well depth, drilling methods, earth materials encountered, the selected method of sampling, etc. The casing diameter should allow free movement of equipment during well flushing and sampling. An example of a typical well casing design is shown in Figure 2-7. For this design, a three inch inner diameter (ID) bailer is selected for sample extraction. The outside bailer diameter was determined in conjunction with the minimum inside casing diameter. The selected ID of the well shown in the Figure is 4 inches.

Site-specific factors (e.g., earth material type and depth to ground water) will also influence well casing selection. Well casing sizes vary accordingly with the particular requirements of the site (e.g., some earth material formations will necessitate use of stronger casing materials).

Intake Portion Design

Proper design of the well intake ensures sufficient quantities of free-flowing water to the well and minimizes the entrance of formation materials (e.g., silt and sediment) into the well. Where well screens are needed, screen design should consider appropriate slot size selection to correspond to the particular formation materials present. Location of the well intake is critical. It should be centered in the most probable contaminant pathway and be short enough that the sample is not always too dilute to detect the presence of the monitored parameters. To enable sample collection at depths where appropriate aquifer flow zones exist, the intake must be located within formation materials which are most likely to yield samples showing any migrating contaminants. On-site investigations should identify the uppermost aquifer flow zones so that well intake location and length can be determined (see Sections 2.2.1, 2.2.2 and 2.2.4). In cases where the flow zone(s) cannot be adequately identified, or

Figure 2-7
Typical Well Casing Design


3" ID
BAILER
4" ID WELL
1/2"
GROUT PIPE
(temporary)
3/4" CLEARANCE
1/4" CLEARANCE
6" ID TEMPORARY CASING

the aquifer is extremely thick, multi-level sampling, (e.g., a cluster of separate wells, screened and sealed at various depths) should be used to obtain representative water samples. Figure 2-8 illustrates the well cluster concept.

Well Materials Selection

When selecting well materials, owners or operators should choose construction materials that have the least potential for affecting the sample. That is, the desired levels of detection for required chemical analyses should be achieved without being unduly impacted by interactions between the well material and the sample. (For further information on selection of well materials with regard to sampling parameters, see Scalf, et al, 1981, pp. 19, 87-93).

An example of a typical monitoring well is shown in Figure 2-9. Only the stainless steel screen and riser pipe are in contact with the ground water. The galvanized pipe is used to case the upper part of the well and is not directly in contact with the ground water. This example does not imply that this design is the most appropriate in all monitoring situations.

2.3.2 Well Construction

Major components of well construction include drilling methods, filter packing, sealing and well development. These components relate to maintaining the integrity of the borehole, enabling sampling in the appropriate aquifer flow zone(s) and preventing the contamination of samples.

Drilling Methods

An owner or operator should choose a drilling method that will minimize the spread of any ground-water contamination and minimize interference with sample chemistry. Site-specific conditions will play an important role in choosing the method. Factors to be considered in choosing a drilling method include:

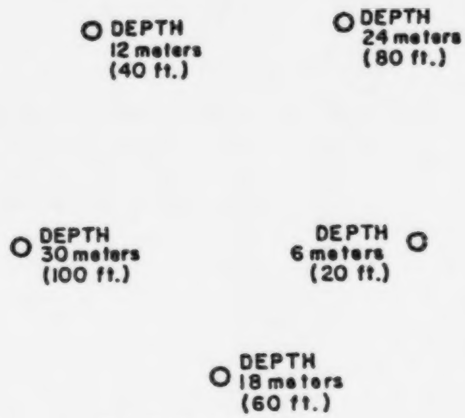
- hydrogeologic environment (related to types of formations, depth of drilling, desired depth of well intake, etc.)

- the required parameter lists as well as the types of potential contaminants to be monitored if the assessment program has begun;

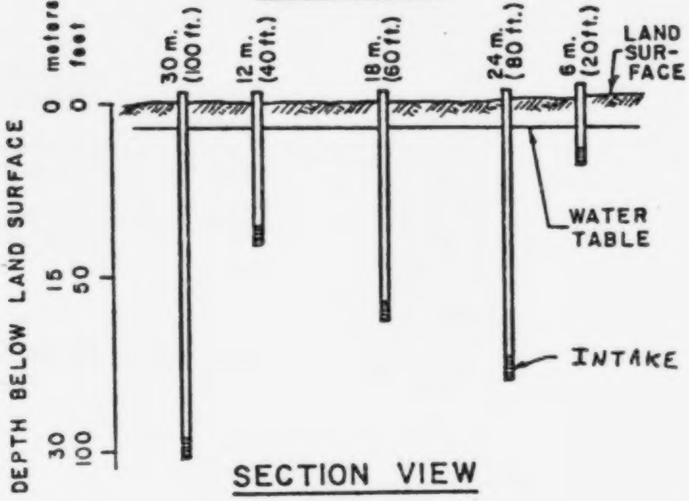
- design of monitoring well desired; and

- availability of drilling equipment.

Figure 2-8
Well Cluster Concept

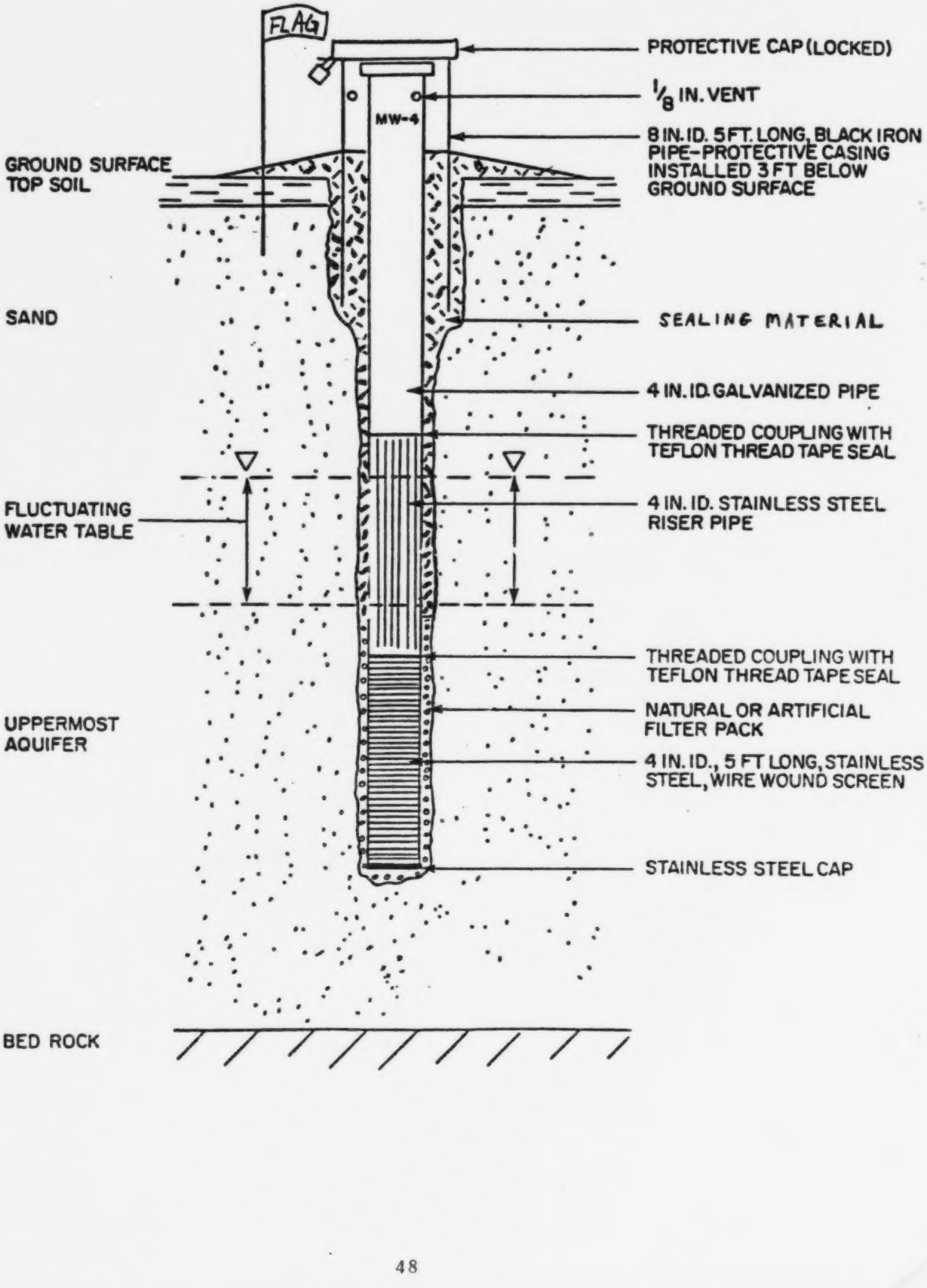

DEPTH 12 meters (40 ft.)
DEPTH 24 meters (80 ft.)
DEPTH 30 meters (100 ft.)
DEPTH 6 meters (20 ft.)
DEPTH 18 meters (60 ft.)

PLAN VIEW


DEPTH BELOW LAND SURFACE
meters
feet
0
0
15
50
30
100
30 m. (100 ft.)
12 m. (40 ft.)
18 m. (60 ft.)
24 m. (80 ft.)
6 m. (20 ft.)
LAND SURFACE
WATER TABLE
INTAKE

SECTION VIEW

Figure 2-9
Typical Monitoring Well Profile


FLAG
MW-4
PROTECTIVE CAP (LOCKED)
1/8 IN. VENT
8 IN. ID. 5 FT. LONG, BLACK IRON PIPE-PROTECTIVE CASING INSTALLED 3 FT BELOW GROUND SURFACE
GROUND SURFACE
TOP SOIL
SAND
SEALING MATERIAL
4 IN. ID. GALVANIZED PIPE
THREADED COUPLING WITH TEFLON THREAD TAPE SEAL
FLUCTUATING WATER TABLE
4 IN. ID. STAINLESS STEEL RISER PIPE
THREADED COUPLING WITH TEFLON THREAD TAPE SEAL
NATURAL OR ARTIFICIAL FILTER PACK
UPPERMOST AQUIFER
4 IN. ID., 5 FT LONG, STAINLESS STEEL, WIRE WOUND SCREEN
STAINLESS STEEL CAP
BED ROCK

A variety of dry and wet (i.e., where drilling fluids are employed) methods are used to drill monitoring wells. Some of the more common methods include mud rotary, air rotary, cable tool, reverse rotary, solid-stem auger, hollow-stem auger and jetting. The advantages and disadvantages of both dry and wet methods are discussed in detail by Scalf, et al (1981, pp. 19-34). In certain situations, dry methods can facilitate the collection of more reliable formation samples and reduce ground-water contamination that could result from drilling fluids used in wet methods. However, some geological conditions may necessitate wet drilling. If wet drilling is performed, special attention must be given to preventing drilling fluids from entering the aquifer flow zones and to removing of any such fluids from formation materials if they do enter by proper well development prior to sampling. Wet drilling methods which utilize organic additives may distort the TOX and TOC concentrations, and thus mask possible ground-water contamination. Drilling fluid should be clear water or bentonite mixed with water. The owner or operator should be prepared to specify and defend the selection of any drilling fluid used with regard to its effects upon sampling parameter analyses. Nearby surface water bodies such as ponds and streams may be contaminated and, therefore, should not be used for drilling fluid purposes unless it can be shown that required analyses will not be adversely affected. The Agency recommends that periodic samples of the fluid used for drilling and washing of the drilling equiment and samples of the recirculated drilling fluid be analyzed for the required parameters and particularly for those listed in §265.92(b)(3).

Drilling equipment should be kept clean and out of contact with the ground surface when not in use. Contamination sources such as hydraulic oil, gasoline, grease and oil from the drill rig should also be removed. Antifreeze, which is commonly pumped into the drilling fluid hoses to keep them from freezing during cold weather, should not be used if it will affect the required analysis. Clean mud pans with easily removable covers should be used in place of mud pits dug into the ground.

Filter Packing

Section 265.91(c) requires that casings be screened or perforated, and packed with gravel or sand where necessary. The owner or operator should evaluate site conditions to determine if natural packing is sufficient or if "artifical" packing is needed. An artifically packed well has gravel or sand placed in the borehole around the outside of the intake area. A naturally developed well is one in which a hydraulically graded zone around the screen is created in the formation itself by repeated surging and bailing or pumping. A well screen located in an aquifer surrounded by hard formation material may not need filter packing if the area remains consolidated when pumping. Whether natural or artifical, the purposes of filter packing are to develop a zone of increased hydraulic conductivity around the intake (e.g., screen) and to prevent well clogging (see Figure 2-10).

Generally, artifical filter packing is needed in unconsolidated formations if the aquifer consists primarily of homogeneous, fine grained sand or silt. Other situations where artificial packing would likely be appropriate include:

- well-graded aquifers containing large percentages of fine materials (to avoid settlement of material above the screen); and

- strata containing poorly cemented sandstone.

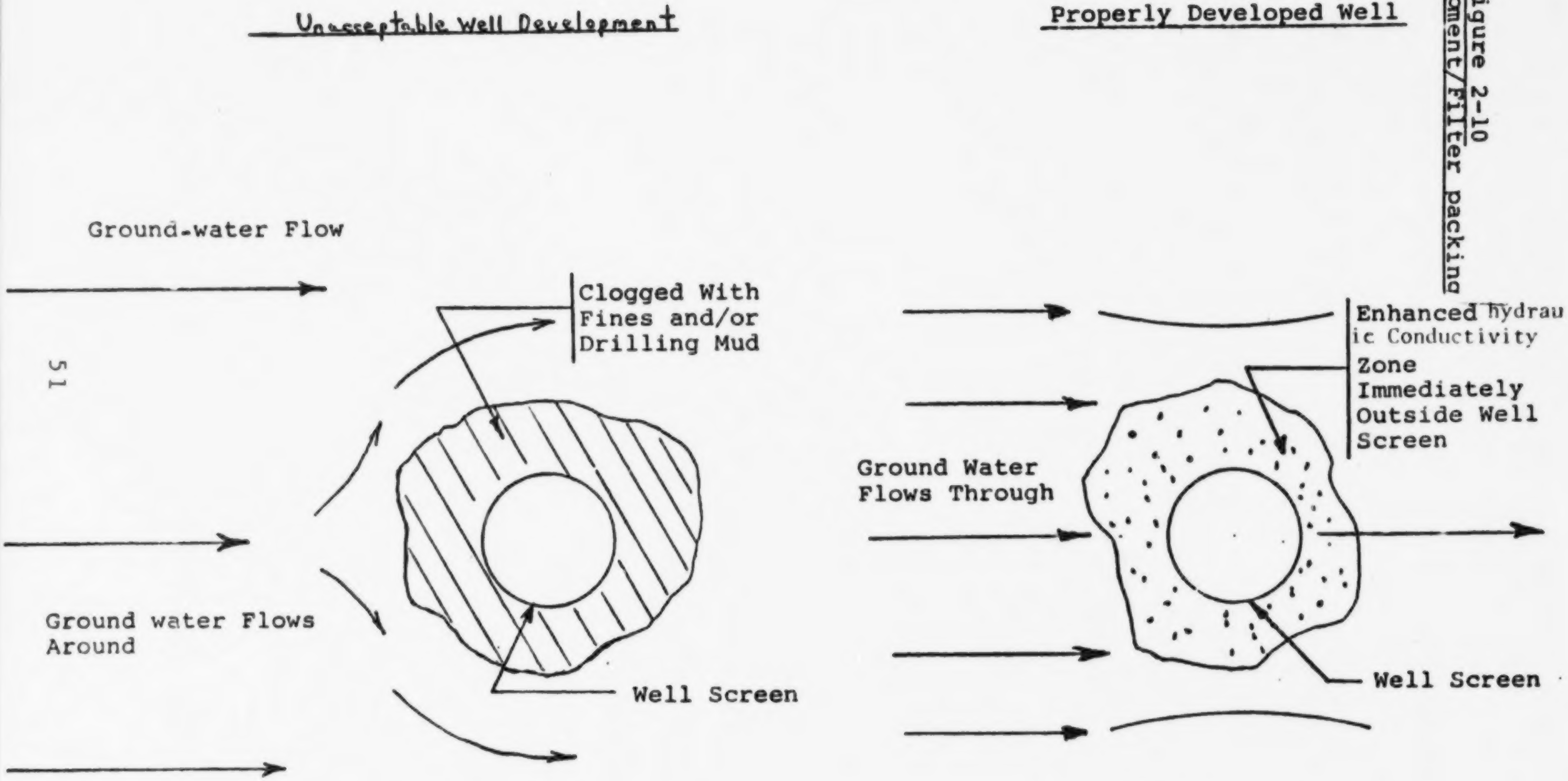
If artificial packing is needed to properly complete a monitoring well, appropriate materials for the filter pack must be chosen. Selecting the filter pack grain size necessitates sampling and grain size analysis of the aquifer materials. Selecting the appropriate filter pack should prevent clogging with fine materials, (e.g., clay, silt). For further information on packing materials and procedures, see EPA, Office of Water Supply (1977, pp. 96-100).

Sealing of Wells

Commonly, during well installation an irregular space between the borehole and casing will result. Section 265.91(c) requires that the annular space be sealed with a suitable material (e.g., cement grout or bentonite slurry) to prevent sample and ground-water contamination. Therefore, it is imperative that an appropriate sealing procedure be initiated to prevent cross-contamination between surface materials and ground water.

Sealing is a process which fills the annular space between the well casing and the borehole, preventing water and other materials from the surface from entering and possibly contaminating the aquifer. Cement grout and bentonite slurry are commonly used as sealing materials. Regardless of the method of sealing selected by the owner or operator, the process must be effective in ensuring a continuous satisfactory seal. For further information on well sealing materials and procedures, see EPA, Office of Water Supply (1977 pp. 79-87).

Figure 2-10
Well Development/Filter packing


Unacceptable Well Development
Ground-water Flow
Clogged With Fines and/or Drilling Mud
Ground water Flows Around
Well Screen
Properly Developed Well
Enhanced hydraulic Conductivity Zone Immediately Outside Well Screen
Ground Water Flows Through
Well Screen

Well Development

Well development is necessary to:

- restore the natural hydraulic conductivity of the formation adjacent to the borehole to permit the water to flow into the intake easily; and
- remove the clay, silt and other fines from the formation so that during subsequent sampling the water will not be turbid or contain suspended matter which can easily interfere with chemical analysis.

There are a variety of suitable methods for developing wells, including surge block, air lift, bailer, and surging and pumping. For further information on these methods, see Scalf, et al; (1981, pp. 36-38). The development process is best accomplished by causing the natural formation water inside the well intake to move vigorously in and out in order to agitate the clay and silt, and move these fines into the screen. The use of water other than natural formation water is not recommended.

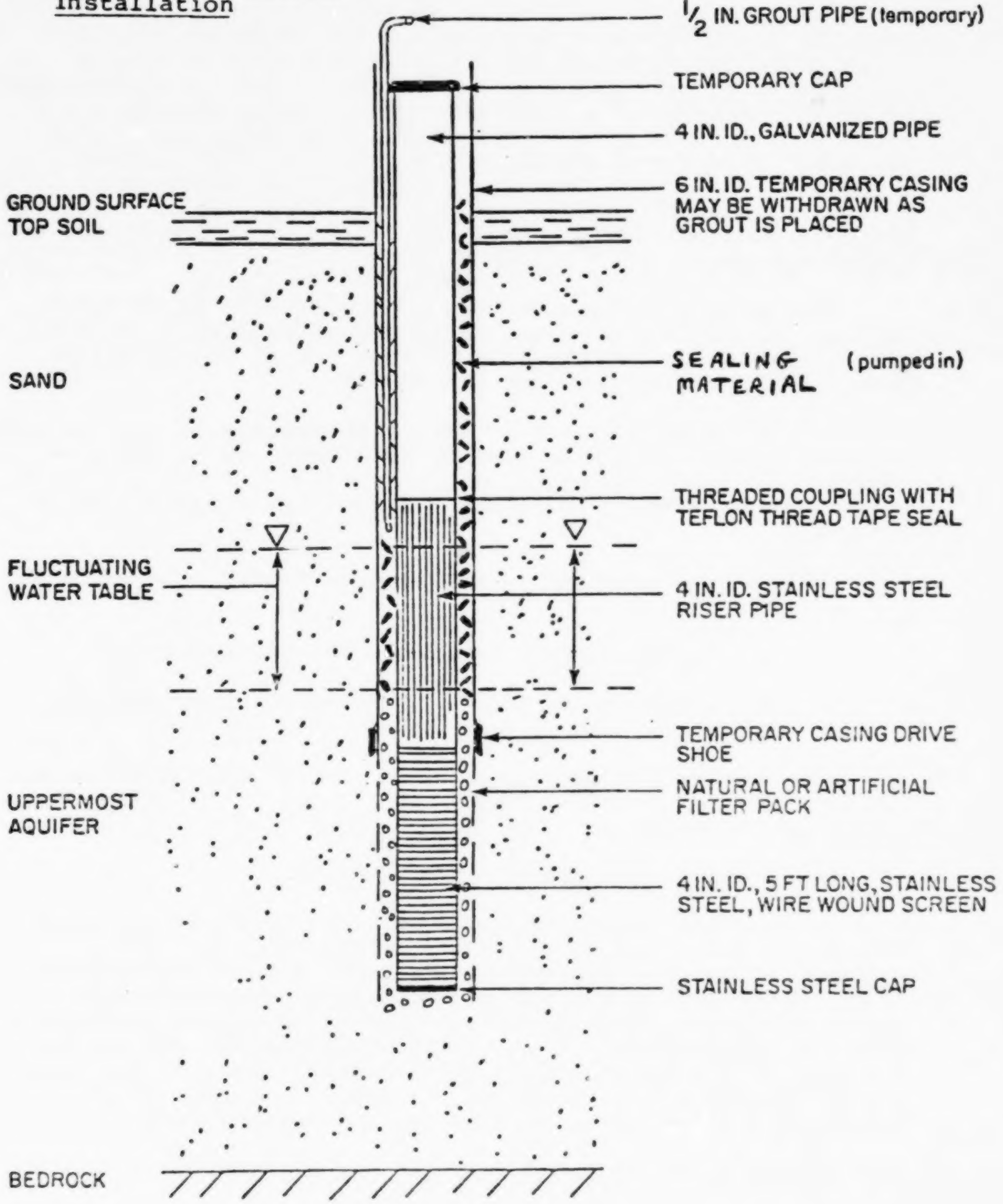
To verify the adequacy of a completed well, the well driller should test the performance of the well (e.g., by pumping or bailing). The well should yield clear water of sufficient volume to more than satisfy the minimum volume required for the sampling program operation (including well flushing). If the well cannot be developed satisfactorily because of improper design or construction or other reasons, it should not be used as a monitoring well. An additional well should be drilled and constructed as a replacement.

Examples of Well Installations

Care should be given to preparation of the casing and intake portion materials prior to installation. As a minimum, both should be washed with a detergent and rinsed thoroughly with clean water. Care should also be taken that these and other sampling materials are protected from contamination by using some type of ground cover such as plastic sheeting for temporary storage in the work area.

Figure 2-11 presents an example of a well installation method. A six inch (ID) temporary casing is driven through the zone to be screened. Upon reaching the desired depth determined by hydrogeologic investigation, the temporary casing is withdrawn and the monitoring well screen and casing placed inside. If an artificial filter pack (e.g., clean sand or gravel) is to be used, it should be emplaced a few feet at a time as the temporary casing is removed. The filter pack materials should extend a few feet above the top of the

Figure 2-11
Example of Monitoring Well
Installation


1/2 IN. GROUT PIPE (temporary)
TEMPORARY CAP
4 IN. ID., GALVANIZED PIPE
6 IN. ID. TEMPORARY CASING MAY BE WITHDRAWN AS GROUT IS PLACED
GROUND SURFACE
TOP SOIL
SAND
SEALING MATERIAL (pumped in)
THREADED COUPLING WITH TEFLON THREAD TAPE SEAL
FLUCTUATING WATER TABLE
4 IN. ID. STAINLESS STEEL RISER PIPE
TEMPORARY CASING DRIVE SHOE
NATURAL OR ARTIFICIAL FILTER PACK
UPPERMOST AQUIFER
4 IN. ID., 5 FT LONG, STAINLESS STEEL, WIRE WOUND SCREEN
STAINLESS STEEL CAP
BEDROCK

screen. A seal made from material such as cement grout or bentonite slurry should be placed in the remaining annular space to protect against the vertical migration of fluids through the annular space to the aquifer. This is accomplished by pumping the material into the annular space through a 1/2 inch ID grout pipe (see Figure 2-11). The temporary casing and grout pipe are gradually removed as the annular space fills with the sealing material. Finally, a 5-foot long, 8-inch ID protective casing with a protective cap is installed over the monitoring well casing to a depth of 3 feet below the ground surface.

The major advantage of this method of well installation is that the temporary casing minimizes contamination because during the entire installation process a seal is maintained between the land surface and the aquifer.

Another common method of well installation is the lowering of casing into a borehole drilled by a solid or hollow stem auger. Although eliminating the possibility of contamination by drilling fluids, this method has some limitations. These include:

- the well diameter is usually restricted to a maximum of 2 inches;
- well depths usually cannot exceed 150 feet; and
- the method is not well suited for drilling through hard formations.

For further information on well installation procedures, see EPA, Office of Water Supply, (1977, pp. 76-77) and Johnson (1975, pp. 209-276).

Well Construction Records

The facility owner or operator should require the well driller to keep records of all materials used, including dimensions, amounts and types. Details of well construction (e.g., depths of screen and casing, depths at which water was encountered, filter pack and sealing materials placement) should be documented. Logs of materials encountered during drilling should be recorded. The facility owner or operator should acquire and maintain at the facility copies of all information relating to well design and installation.

2.4 Sampling and Analysis

The sampling and analysis requirements of §265.92 are to obtain and analyze representative samples of ground water upgradient and downgradient from the waste management area in order to determine whether the facility has affected ground-water in the uppermost aquifer underlying the facilty. Analyses of three groups of parameters during the first year of monitoring provide data on background water quality. Information from upgradient well analyses of one of these groups (i.e., the ground water contamination indicators) serves as initial background data for statistical comparison to data collected after the first year of monitoring at each individual monitoring well.

2.4.1 Sampling and Analysis Plans

§265.92(a) requires the owner or operator to develop and follow a ground-water sampling and analysis plan. The plan must be kept at the facility and must include procedures and techniques for:

- sample collection;
- sample preservation and shipment;
- analytical procedures; and
- chain of custody control.

The sampling and analysis plan must be available to EPA personnel upon facility inspection. Its format should allow prompt review of the determinants of the program's capabilities such as the following:

- that the sampling schedule reflects seasonal influences, unusual ground-water flow rate situations;
- rationale for sample handling and preparation (e.g., filtering or not filtering); consistency;
- flushing volume appropriateness--sufficient to provide "representative" samples yet not dilute:
- extraction methods compatible with parameters of interest;
- storage and transit methods compatible with parameters of interest; and
- reasonable assurance of chain of custody.

2.4.2 Sample Collection

The following guidance is provided to ensure the collection of representative samples through minimizing the introduction of extraneous substances to the sample. (For additional guidance on withdrawing samples, see Scalf, et al, 1981, p. 44.) Also, water level measurement techniques are described.

Water Level Measurement

§265.92(e) requires that elevation of the ground-water surface at each monitoring well be determined each time a sample is obtained (i.e., for each sampling event). The initial step (before well flushing and sample withdrawal) in the sampling program is to measure the static water level in each monitoring well. The measuring instrument should be free of contaminants and should not be allowed to come in contact with the ground. The water level should be measured accurately (e.g., to the nearest 0.01 meter). Accurate measurement of the water level in the monitoring wells is important for several reasons, including:

- determining the hydraulic gradient of the ground water in the vicinity of the disposal facility;
- monitoring of seasonal changes in the water table;
- evaluating effects on the uppermost aquifer of water supply well pumping near the facility, including any modification in the direction of flow; and
- determining the existence of a "ground-water mound" (elevated water table) developing in the aquifer beneath the facility site. This is important since mounding could cause the flow of potentially contaminated water in directions other than towards the "downgradient" monitoring wells.

A variety of mechanical and electrical instruments are available for the measurement of the water level in monitoring wells. Mechanical methods usually involve lowering a measuring tape or marked line into the well, withdrawing it, and measuring the distance to the "wet spot". A variation of this method includes attaching a mechanical sounding device to the measuring tape, lowering the tape into the well until a sound is heard, and noting the length of measuring tape lowered into the well. Electronic instruments are also available for measuring the water level in the monitoring well. Use of an electronic instrument involves lowering a cable into the well until it reaches water, at which point the electric circuit is closed. Water levels are recorded by a meter at the surface. For further information on measuring of water surface elevations see EPA, Office of Water Supply (1977, pp. 116-117) and Johnson (1975, pp. 88-91).

Well Flushing.

Monitoring wells should be flushed prior to sample withdrawal to avoid collection of a non-representative (i.e., stagnant or stratified) ground-water sample. A common procedure is to pump or bail a consistent volume of four to 10 times the volume of water standing in the well (for moderate to high yield formations) and at least one times the volume (for low yield formations) prior to sampling to ensure that water representative of the aquifer has entered the well. Flushing equipment selected should affect parameter analysis to the least possible degree. For further information on this topic, see Scalf, et al (1981, pp. 43-44).

Obtaining Samples

Sampling equipment can be selected from a variety of possible devices for the routine withdrawal of water samples from ground-water monitoring wells. However, once selected, all statistically compared values should be made with the same equipment and procedures. Bailers, portable submersible pumps, air-lift samplers, and suction-lift pumps have been commonly used for ground-water investigations when monitoring in the milligrams per liter range of detection or higher. However, when monitoring of trace constituents in the low micrograms per liter range of detection or lower, several possible interferences, normally insignificant at a higher level of detection, may occur from the use of standard sampling equipment. Owners or operators should consider the likelihood that the assessment program will be concerned with trace organics, for instance, and whether the detection program sampling equipment and monitoring wells will be useful during the assessment. Problems to be avoided when using conventional sampling equipment include:

- leaching of materials used in the construction of sampling equipment into the sample (e.g., trace levels of adhesives);

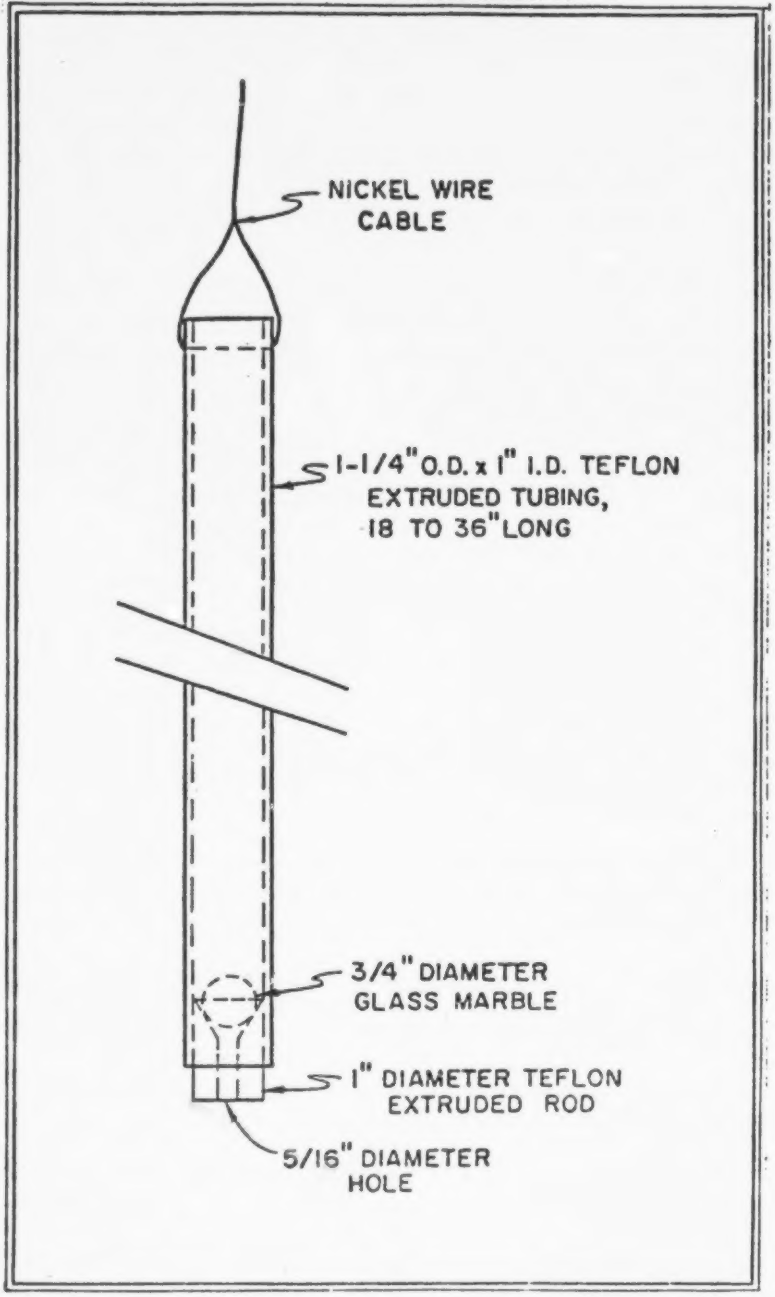
- adsorption of organic constituents in the sample on sampling equipment (e.g., organic constituents can become adsorbed on PVC);

- pumps may introduce trace oils or metals to the sample (e.g., lubricants); and

- excessive mixing of the sample with air may occur, driving volatile constituents from the sample.

The teflon bailer (see Figure 2-12) is recommended when monitoring for total organic halogen and is appropriate for

Figure 2-12
Teflon Bailer for Ground-water Sampling


NICKEL WIRE CABLE
1-1/4" O.D. x 1" I.D. TEFLON EXTRUDED TUBING, 18 TO 36" LONG
3/4" DIAMETER GLASS MARBLE
1" DIAMETER TEFLON EXTRUDED ROD
5/16" DIAMETER HOLE

Source: Scalf, et al (1981)

sampling of all required parameters in §265.92(b). Other appropriate equipment used for sampling of ground water and the advantages and disadvantages of each are discussed by Scalf, et al. (1981, pp. 44-60, 87-93), including some newer and more sophisticated sampling equipment for low level constituent analyses. This equipment includes: nitrogen powered, glass-teflon pump; system for grab sampling; and a continuous sampling system for organics.

The major concern in selecting sampling equipment is that it ideally should not alter or contaminate the sample. The selection of sampling equipment should be geared to the nature of the parameters of interest. Scalf, et al (1981, pp. 87-91) present a "Summary of Procedures Based on Parameter of Interest" which offers guidelines for sampling for various categories of contaminants. This summary includes all detection program parameters. Sampling equipment should be appropriately cleaned before sampling at each well.

2.4.3 Sample Preservation

Preservation techniques serve to slow down or delay chemical and biological action, retard hydrolysis of chemical compounds and complexes, reduce volatility of constituents and reduce absorption effects. General preservation methods include pH control, chemical addition, refrigeration, and freezing. Other practices which may aid in retaining a representative sample for given parameter analyses include: preventing light from penetrating the sample, filling the bottle completely to eliminate headspace; and shipping to a laboratory to analyze the sample as soon as possible after collection. Specific preservatives, container types and holding times, as described in the selected analytical procedures, should be used to maintain sample integrity. Whatever methods an owner or operator selects should be recorded and standardized for all subsequent sampling at the facility.

2.4.4 Sample Shipment

The shipment of ground-water samples necessitates the use of containers and packing materials designed to prevent breakage, spills and contamination of the samples. Tight packing material (e.g., 10 cm) should be provided around each sample container. Samples requiring refrigeration should be placed in water-proof containers and packed with re-usable plastic freezer packs, cans of freezing gel or ice. Containers should be securely sealed, clearly labeled, compatible with the sample and of sufficient volume (as described in the selected analytical procedures); and accompanied by a sample analysis request sheet and chain of custody record. Shippers of samples should abide by any applicable shipping regulations (e.g., restrictions due to use of chemical preservatives).

2.4.5 Analytical Procedures

The facility owner or operator should select analytical procedures which will provide results which most truly represent the effects of his facility on ground water. Properly installed and developed monitoring wells should minimize the entrance of undissolved solids into the well intake. However, any remaining undissolved solids which may interfere with analytical procedures or which may be incompatible with analytical equipment should be removed prior to analysis.

For metals. except where the anaytical technique requires otherwise, the Agency recommends that analyses be performed by the "total recoverable" procedure, as described in Methods for Chemical Analysis of Water and Wastes (Section 4.1.4, pp. "Metals-6-7" of the metals discussion) (See Table 2-3 for full reference). This procedure will yield a "total" concentration value in a sample which has not been filtered before acidification. Likewise, for other inorganic parameters, sample preparation should be based on measuring the total effect of each parameter on the sample. There may be some unique situations where, for instance, concentrations determined by the total recoverable procedure may not represent the facility impact. When dissolved concentrations are used, the owner or operator should be prepared to demonstrate his rationale.

For organic parameters, undissolved solids should be separated out before sample analysis when appropriate for the chosen analytical procedure. Separatory techniques include settling, centrifugation and filtration. When filtration is employed, procedures should be designed to prevent the loss of volatile organic constituents.

In any case, consistency in sample preparation and analytical procedures must be established and recorded.

§265.92(b) requires the owner or operator to determine the concentrations or values of three groups of parameters in ground-water samples. A discussion of the importance of these parameters and sampling frequency is given below:

Parameters characterizing the suitability of the ground water as a drinking water supply:

- Arsenic
- Barium
- Cadmium
- Chromium
- Fluoride
- Lead
- Mercury
- Nitrate (as N)
- Selenium
- Silver
- Endrin
- Lindane
- Methoxychlor
- Toxaphene
- 2, 4-D
- 2, 4, 5-TP Silvex
- Radium
- Gross Alpha
- Gross Beta
- Coliform bacteria

Table 2-3

Analytical References

Note: The references given below (some containing approved methods from other EPA programs) provide methods which have not undergone rigorous formal testing on ground-water monitoring well samples. The Agency, however, is of the opinion that these methods are appropriate for Subpart F monitoring purposes. Therefore, the following or other appropriate references should be used:

- Methods for Chemical Analysis of Water and Wastes (EPA-600/4-79-020); Environmental Monitoring and and Support Laboratory (EMSL); Cincinnati, Ohio; March 1979.†
- Inductively Coupled Plasma - Atomic Emission Spectrometric Method For Trace Element Analysis of Water and Wastes - Method 200.7; EMSL; Cincinnati, Ohio.†
- Methods for Organochlorine Pesticides and Chlorophenoxy Acid Herbicides In Drinking Water and Raw Source Water (Interim); EMSL; Cincinnati, Ohio; July 1978.†
- Prescribed Procedures for Measurement of Radioactivity in Drinking Water (EPA-600/4-80-032); EMSL; Cincinnati, Ohio; August 1980.†
- Microbiological Methods for Monitoring the Environment (EPA 600/8-78-017); EMSL; Cincinnati, Ohio, December 1978. †

(Table 2-3 continued)

- Total Organic Halide (TOX) - Adapted From Method 450.1 Interim (EPA 600/4-81-056); EMSL; Cincinnati, Ohio; November 1980.*
- 41 FR 52780 et seq; Guidelines Establishing Test Procedures for the Analysis of Pollutants; Amendments- December 1, 1976;
- 41 FR 59566 et seq; National Interim Primary Drinking Water Regulations - December 24, 1975.
- 41 FR 28402 et seq; Interim Primary Drinking Water Regulations, Radionuclides - July 9, 1976.
- 45 FR 57332 et seq; Interim Primary Drinking Water Regulations; Amendments - August 27, 1980.
- Standard Methods for the Examination of Water and Wastewater. Current edition. American Public Health Association, et al. Washington, D.C.
- Annual Book of ASTM Standards, Part 31, "Water". 1976.
- Test Methods for Evaluating Solid Waste (SW-846). U.S. EPA, Office of Solid Waste and Emergency Response. Washington, D.C.; Second Edition, July 1982.°

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* This interim methodology for determination of "Total Organic Halogen" appears as Appendix D.

† Available from:

Environmental Monitoring and Support Laboratory
Office of Research and Development
U.S.Environmental Protection Agency
26 W. St. Clair Street
Cincinnati, Ohio 45268

° Available from:

U.S. Government Printing Office, Washington, D.C.

These parameters are used to determine the general suitability of the aquifer as a drinking water supply. The parameters listed have been established under the Safe Drinking Water Act as National Interim Primary Drinking Water Standards.

Frequency

Owners or operators are required to sample and analyze for these parameters quarterly during the first year of monitoring only. Although these parameters require sampling for only one year, owners or operators may continue to monitor these parameters on a longer and/or more frequent basis to provide a more thorough characterization of the aquifer.

Analytical Methods (see Table 2-3)

Parameters used to characterize ground-water quality:

- Chloride
- Iron
- Manganese
- Phenols (Phenolics, Total Recoverable)
- Sodium
- Sulfate

These substances are ubiquitous in the environment and are often used to characterize the suitability of a ground-water supply for a variety of uses. Information on these parameters will also be useful in any assessment of ground-water contamination that follows a determination that the facility is affecting ground-water quality.

Frequency

Owners or operators are required to sample and analyze for these parameters quarterly for the first year and at least annually for all subsequent years.

Analytical Methods (see Table 2-3)

Parameters Used as Indicators of Ground-water Contamination:

- pH
- Specific Conductance
- Total Organic Carbon
- Total Organic Halogen (TOX)

These four indicator parameters reflect changes in the organic and inorganic makeup of the ground water and are used to detect if a facility may be affecting ground-water quality.

Frequency

Owners or operators are required to sample and analyze for these parameters quarterly for the first year to establish initial background concentrations. For all subsequent years, sampling and analysis must be conducted at least semi-annually. Owners or operators may monitor these parameters on a more frequent basis to provide for more prompt detection.

Analytical Methods (see Table 2 -3)

Specific conductance and pH can be analyzed in the field using portable test meters. Exposure to the atmosphere, temperature change, and the addition of preservatives can initiate changes in these parameters. Since pH is more sensitive to such conditions than specific conductance, pH should be determined in the field. Specific conductance may be determined in the field or in the laboratory. Battery operated meters are available. Newer models may be equipped with digital display. Kits are usually complete with probes and standardizing/calibrating solutions. Operation is simple, usually involving calibrating prior to testing which involves immersing a probe in the ground-water sample and reading the output on a meter. Separate pH, specific conductance and temperature test meters are available as well as multi-function meters. The owner or operator should be aware of and consistently perform any temperature corrections for pH and specific conductance called for in the selected analytical procedures.

2.4.6 Coordination Between Sample Collector and Laboratory

In order to ensure the successful implementation of the sampling and analysis requirements, the sample collector and laboratory personnel should closely coordinate their functions with regard to materials and procedures (e.g., providing appropriate sizes, types and numbers of sample containers; preservation materials; sample holding times, delivery arrangements, etc.).

2.4.7 Field Log Book

The owner or operator should maintain a field log book to record information about each sample collected during the ground-water monitoring program. This record of field sampling procedures, measurements, and observations will provide a source of documentation that sampling requirements for the ground-water monitoring program have been met. The field log book should also serve as a reference of past procedures for the person who is sampling. Any change in procedure should be noted. If a change is required, the owner or operator should decide if a re-determination of initial background parameter levels is necessary.

A standard format of log entries should be established in order to insure that all required information is noted. Each field effort should include, but need not be limited to, the following information:

- facility name and address;
- name of sample collector;
- purpose of sample and type (e.g., required analyses for initial background data);
- location(s) or source of sampling (e.g., monitoring well number);
- time and date of sampling;
- pertinent well data (e.g., depth, water surface elevation);
- sampling method (e.g., bailer, suction-lift pump);
- preservation used (if any) - type;
- log number of each sample, volume, and container type;
- appearance of each sample (e.g., color, turbidity, sediment, oil on surface);
- field observations/sampling conditions (e.g., weather);
- sample temperature upon sampling;
- analyses performed in the field:
  - ° pH
  - ° specific conductance (unless done only at lab);
- sample storage (e.g., where, how; conditions such as heat and light, number of sample seal); and
- name and location of laboratory performing analyses.

At the conclusion of this decription of the field activities, the sample collector should verify the entries and sign the log book. The responsibility for preparing and storing the field log books should be assigned to a person who is knowledgeable and involved in the monitoring program.

2.4.8 Chain of Custody Control

A procedure for chain of custody control, or persons through whom samples were transferred, is a required part of the sampling and analysis plan. This procedure should document sample transfer from collection through storage, shipment and analysis. An accurate written record of these events should demonstrate sample possession throughout the entire program and, along with the proper use of sample container seals, should show that sample integrity was maintained.

An example of a chain of custody record form is given in Figure 2-13. One form should be used for as many samples as possible, preferably for a certain "set" of samples (e.g., those from one well). The chain of custody form should be signed and dated under "Chain of Possession" each time the samples noted on that form change hands. Prompt attention to this procedure will aid in keeping an accurate record of sample transfer. The facility owner or operator should arrange for each sample handler to return a copy of the form to the facility.

Analysis request sheets (as many as necessary) should accompany the samples delivered to the laboratory. The analysis requests serve as official communication to the laboratory of the particular analysis(es) required for each sample and further verify that the chain of custody is complete. A copy should be returned to the owner or operator of the facility. An example of a standard analysis request sheet is given in Figure 2-14. A more comprehensive request form may be used, if necessary. The laboratory may supply analysis request sheets to the sampler.

2.4.9 Laboratory Selection

Analyses of the ground-water samples should be performed by a competent laboratory. In selecting a laboratory (or laboratories) the owner or operator should evaluate its capability to perform analyses for the required monitoring parameters (e.g., does it have the instrumentation needed to perform the total organic halogen analysis?). In assessing laboratory capabilities, the owner or operator may wish to determine whether the laboratory performs analyses required under other EPA regulatory programs (e.g., National Pollutant Discharge Elimination System; Safe Drinking Water Act). Laboratory selection should also include a detailed evaluation of the laboratory's quality control program. For further information on this topic, see Handbook for Analytical Quality Control in Water and Wastewater Laboratories (EPA-600/4-79-019), EMSL, March 1979 (available from EMSL; see Table 2-3 for address).

Figure 2-13
Example of Sample Chain of Custody Form

Collector's Sample Nos. ________
____
____
____

Company's Name ______________________ Telephone (__) ________

Address ____

number street city state zip

Collector's Name ______________________ Telephone (__) ________

Date Sampled ______________ Time Sampled ______________ hours

Field Information ____

____

____

____

Sample Allocation:

1. ____
name of organization

2. ____
name of organization

3. ____
name of organization

Chain of Possession

1. ________	________	________	________
signature	title	inclusive	dates
2. ________	________	________	________
signature	title	inclusive	dates
3. ________	________	________	________
signature	title	inclusive	dates

Figure 2-14
Example of Sample Analysis Request Form

HAZARDOUS WASTE MANAGEMENT FACILITY

Collector________ Date Sampled______ Time___hrs
Facility________________________
Address________________________
Telephone__________ Company Contact_______

LABORATORY

Received by________ Title______ Date____
Laboratory________________________
Address________________________

ANALYSIS REQUESTED

Sample No.	arsenic	barium	cadmium	chromium	fluoride	lead	mercury	nitrate (as N)	selenium	silver	endrin	lindane	methoxychlor	toxaphene	2,4-D	2,4,5-TP silvex	radium	gross alpha	gross beta	coliform bacteria	chloride	iron	manganese	phenols	sodium	sulfate	specific conductance	pH	TOC	TOX

2.5 Program Implementation

2.5.1 Sampling Schedule

Ground-water sampling for the detection program is scheduled in two phases:

- initial background sampling for a period of one year for:
    - ° measurement of the ground-water surface elevation for each sampling event;
    - ° parameters characterizing the suitability of the ground water as a drinking water supply;
    - ° parameters establishing ground-water quality; and
    - ° parameters used as indicators of ground-water contamination (four replicates for each upgradient well).
- sampling after the first year for:
    - ° measurement of the ground-water surface elevation each time a sample is obtained;
    - ° parameters establishing ground-water quality;
    - ° parameters used as indicators of ground water contamination (four replicates for each upgradient and downgradient well).

Initial background sampling should be performed during the period of November 19, 1981 through November 18, 1982 for interim status facilities. The overall schedule for the detection program is summarized in Figure 2-15. Detection program sampling after the first year should continue until final closure of the facility (and for disposal facilities until the end of the post-closure care period) or until a ground-water quality assessment program is begun (see Section 3).

There are certain situations in which it would be advisable to sample more frequently than the required minimum or to amend the sampling schedule in order to detect significant effects upon the ground-water quality. Such situations include:

Figure 2-15
Minimum Sampling Frequency Required for the Detection Program

First Year

Month test parameter	1	2	3	4	5	6	7	8	9	10	11	12
drinking water suitability	X			X			X			X		
groundwater quality	X			X			X			X		
contamination indicators	X			X			X			X		
groundwater surface elevation	X			X			X			X		

After the First Year

Month test parameter	1	2	3	4	5	6	7	8	9	10	11	12
groundwater quality	X											
contamination indicators	X						X					
groundwater surface elevation	X						X					

- high ground-water flow rate situations. The ground-water flow rate is a major factor influencing the rate at which contaminants may migrate in the subsurface environment. The higher the ground-water flow rate the more frequently sampling is recommended (e.g., turbulent flow in fractures or solution cavities). Flow rates in different types of aquifers can range from a few meters per year to tens of meters per day. (See Section 3.2 for information on measurement of ground-water flow rate and evaluation of subsurface factors influencing flow rates);

- changes in ground-water flow direction. Changes in flow direction can affect the ability of "upgradient" and "downgradient" wells to adequately determine the facility's effect on ground-water quality in the uppermost aquifer. If such changes in flow direction occur, then the monitoring system must be re-evaluated and, if necessary, redesigned such that it meets the monitoring performance standard in §265.90(a);

- significant climatic changes. Characteristics of the climate (e.g., precipitation or evapotranspiration) will influence leachate generation, which would be expected to accelerate during ground-water recharge periods. Ground-water monitoring can be most effective if it responds to these recharge periods. Due to this consideration, the sampling schedule might be altered with respect to frequency (e.g., instituting monthly sampling as opposed to semi-annual) and/or periodicity (e.g., sampling once in March, April, May and June, then in October in addition to regular frequency sampling). A situation in which more frequent sampling should be considered is after an extended period of above average precipitation during which leachate generation would be expected to accelerate or to become more dilute;

- gradual changes in monitoring data. A noticeable trend (as opposed to a statistically "significant change") in monitoring results may warrant more frequent sampling in order to keep abreast of the apparently changing condition of the ground water;

- waste type influences. Waste that is highly soluble in water and/or mobile in soil may travel quickly in the subsurface environment. A facility owner or operator managing such waste should consider sampling more frequently than the minimum; and

- an "unusual" event at the facility (e.g., improper dumping of a large amount of liquids or a visible spill or discharge may indicate the need for more frequent monitoring).

2.5.2 Statistical Analysis

The owner or operator of a facility must perform a statistical analysis of the concentrations or values of the indicator parameters, as determined from the sampling and analysis of the required monitoring wells. If the analytical results for Total Organic Carbon and TOX are reported by the laboratory as below detection limits, then the owner or operator should use values of one milligram per liter for Total Organic Carbon and five micrograms per liter for TOX in the statistical analysis.

Section 265.92(c)(2) on sampling and analysis requires that the initial background mean and variance for each indicator parameter be determined by pooling the replicate measurements for the respective parameter concentrations in samples obtained from the upgradient well(s) during the first year. Replicate analyses are not required for downgradient wells during the first year.

After the first year of monitoring, §265.92(d)(2) on sampling and analysis and §265.93(b) on preparation, evaluation, and response require the owner or operator to analyze for and calculate the mean and variance of each indicator parameter (i.e., pH, Specific Conductance, Total Organic Carbon, and Total Organic Halogen), based on at least four replicate measurements on each sample, for each well in the monitoring system. Results for each indicator parameter from each sampling event (for each and every well in the monitoring system) must be compared with the initial background mean (i.e., that established for the upgradient well(s) during the first year). The student's t-test at the 0.01 level of significance must be used to determine statistically significant increases (or decreases also, in the case of pH) over the initial background values.

First Year Statistical Analysis

During the first year, the initial background mean and variance for each indicator parameter must be determined for samples from upgradient wells.

Arithmetic Mean

In order to perform the t-test, the raw data from the background and monitoring wells must be reduced to specific summary measures. These measures are the mean (an average) and the variance (a measure of variability of the data). For any set of data the mean ($\overline{X}$) is equal to the sum of the measurements divided by the number of measurements (n).

The indicator parameter values for all four quarters of the first year are used to calculate the mean. If more than one upgradient well is being used, the owner or operator must calculate the overall mean value (of each indicator parameter) for all of the upgradient wells. This can be accomplished by summing the data from all of the upgradient wells and dividing this sum by the total number of measurements for each parameter. These first-year upgradient mean values are important since they establish the initial background concentrations to which all subsequent upgradient and downgradient concentrations or values will be compared.

Variance

The variance is an average of the squares of the differences between the actual value and the mean, and is a measure of variability. The mean and variance are used in the Student's t-test to determine whether any changes in the concentration of the indicator parameters are statistically significant. In this context, the variance may be defined as: the sum of the squares of the differences of the individual measurements and the mean, divided by one less than the number of measurements. Symbolically, the sample variance is calculated as follows:

$$s^2 = \frac{\sum_{i=1}^{n} (X_i - \overline{X})^2}{n - 1}$$

where s^2 = sample variance;

X_i = value of each measurement;

$\overline{X}$ = mean of the measurements;

Σ = "the sum of" a set of numbers from the first value (where $i = 1$) to the last value (where $i = n$). In this case, the squared differences of the measurements and the mean are added; and

n = the number of measurements.

For example, in determining the sample variance of the background value of the pH of an upgradient well for the first year, the owner or operator would proceed in the following manner:

- Substract the mean pH value (e.g., 6.4) from each pH measurement, square this value, and sum the squared differences as follows:

	Measurement	Mean	Difference	Squared Difference
1st Quarter	5.7	6.4	-0.7	0.49
	6.3	6.4	-0.1	0.01
	6.8	6.4	0.4	0.16
	4.8	6.4	-1.6	2.56
2nd Quarter	7.5	6.4	1.1	1.21
	8.2	6.4	1.8	3.24
	6.9	6.4	0.5	0.24
	6.1	6.4	-0.3	0.09
3rd Quarter	5.7	6.4	-.07	0.49
	4.3	6.4	-2.1	4.41
	5.5	6.4	-0.9	0.81
	6.2	6.4	-0.2	0.04
4th Quarter	4.7	6.4	-1.7	2.89
	8.6	6.4	2.2	4.84
	8.9	6.4	2.5	6.25
	6.0	6.4	-0.4	0.16
			Total	27.90;

- Divide the sum of the squared differences by the number of measurements minus one, as follows:

Sample Variance = $s^2 = \frac{27.9}{n-1} = \frac{27.9}{16-1} = 1.86$; and

- Keep at least two decimal places for accuracy in calculations.

The variance for specific conductance, total organic carbon, and total organic halogen can be calculated in a similar manner. If more than one upgradient well is being used, the sample variance can be calculated by pooling all the measurements (for each indicator parameter) to determine the mean, subtracting the mean from each measurement, squaring and summing the differences as in the first step above, and dividing this sum by the number of measurements minus one, as in the second step above.

Subsequent Statistical Analysis (after the first year)

After determining initial background values during the first year, the owner or operator must, at least semi-annually, calculate the sample mean and sample variance for four replicate measures (necessitating four aliquots from the same sample for any destructive analyses) of pH, specific conductance, total organic carbon, and total organic halogen, for each upgradient and downgradient ground-water monitoring well. (The regulations allow for a greater sampling and analysis frequency than the minimum, hence providing an opportunity to lessen the prospect of false positive indications of facility impact on ground water.) These values should be determined in the manner described previously. The mean of each of these indicator parameters for each upgradient and downgradient well must be individually compared to the initial background mean for each indicator parameter by using the Student's t-test at the 0.01 level of significance. This provides a determination of statistically significant increases (or decreases also for pH) over the initial background level.

Student's t-test

[Note: The methodology for application of the Student's t-test presented in this guidance document differs from that offered in the May 2, 1980, background document for ground-water monitoring. Although both methods could be appropriate, the one recommended in this guidance document is preferred.]

The Student's t-test is a statistical method used to determine the significance of a change between initial background and subsequent parameter values and must be calculated at least semi-annually for each well for each indicator parameter. Using all the available background data (n_b readings), calculate the background mean ($\overline{X}_b$) and background variance (s_b^2). For the single monitoring well under investigation (n_m readings), calculate the monitoring mean ($\overline{X}_m$) and monitoring variance (s_m^2).

The t-test uses these data summary measures to calculate a t-statistic (t^*) and a comparison t-statistic (t_c). The t^* value is compared to the t_c value and a conclusion reached as to whether there has been a statistically significant change in the indicator parameter value.

The t-test for the difference of two groups is given by:

$$t^* = \frac{\overline{X}_m - \overline{X}_b}{\sqrt{\frac{s_m^2}{n_m} + \frac{s_b^2}{n_b}}}$$

If the t* is negative (except for pH), then there is no significant difference between the monitoring data and background data.

The t-statistic (t_c) against which t* will be compared, necessitates finding t_b and t_m from Table 2-4 where,

t_b = Table 2-4 with (n_b-1) degrees of freedom, 0.01 level of significance; and

t_m = Table 2-4 with (n_m-1) degrees of freedom, 0.01 level of significance.

[NB: if pH is being examined, use 0.005 as the level of significance]. Finally, the special weightings W_b and W_m are defined as:

$$W_b = \frac{s_b^2}{n_b} \quad \text{and} \quad W_m = \frac{s_m^2}{n_m},$$

and so the comparison t-statistic is

$$t_c = \frac{W_b t_b + W_m t_m}{W_b + W_m}.$$

The t-statistic (t*) is now compared with the comparison t-statistic (t_c) using the following decision-rule:

If t* is equal to or larger that t_c, then conclude that there most likely has been an increase in indicator parameter. [In the case for pH, it is decrease if the t* as originally calculated was negative, and increase if the original t* was positive.]

If t*is less than t_c, then conclude that most likely there has not been a change in indicator parameter.

The procedure described above is known as Cochrans' Approximation to the Behrens-Fisher solution of the comparison of two independent samples with unequal population variances. For further information, see Snedecor and Cochran (1967) or Steel and Torrie (1960).

Example of the t-test

These readings represent TOC values collected from a hazardous waste disposal facility. Background well samples

Table 2-4

The Critical t-values at the 0.01 and 0.005 Levels of Significance

Degrees of Freedom	Level of Significance = 0.01	Level of Significance = 0.005
1	31.821	63.657
2	6.965	9.925
3	4.541	5.841
4	3.747	4.604
5	3.365	4.032
6	3.143	3.707
7	2.998	3.499
8	2.896	3.355
9	2.821	3.250
10	2.764	3.169
11	2.718	3.106
12	2.681	3.055
13	2.650	3.012
14	2.624	2.977
15	2.602	2.947
16	2.583	2.921
17	2.567	2.898
18	2.552	2.878
19	2.539	2.861
20	2.528	2.845
21	2.518	2.831
22	2.508	2.819
23	2.500	2.807
24	2.492	2.797
25	2.485	2.787
26	2.479	2.779
27	2.473	2.771
28	2.467	2.763
29	2.462	2.756
30	2.457	2.750
40	2.423	2.704
60	2.390	2.660
120	2.358	2.617
	2.326	2.576

Adapted from Table III, Statistical Tables for Biological, Agricultural and Medical Research, Fisher and Yates, 1963.

were collected quarterly and four determinations made on each quarterly sample. For the purposes of this example, only one monitoring well will be considered.

BACKGROUND WELL 1st Quarter	 2nd Quarter	 3rd Quarter	 4th Quarter	MONITORING WELL
20	12	15	6	42
15	12	16	9	43
15	13	14	10	38
19	13	15	9	36

For the background data the mean ($\overline{X}_b$) is,

$$\overline{X}_b = \frac{20 + 12 + 15 \ldots + 9}{16}, \text{ or}$$

$$\overline{X}_b = 13.31$$

and the background variance (s_b^2) is,

$$s_b^2 = \frac{(20-13.31)^2 + (12-13.31)^2 \ldots + (9-13.31)^2}{16 - 1},$$

or

$$s_b^2 = 13.43$$

For the monitoring data, the mean ($\overline{X}_m$) is,

$$\overline{X}_m = \frac{42 + 43 + 38 + 36}{4}, \text{ or}$$

$$\overline{X}_m = 39.75$$

and the monitoring variance (s_m) is

$$s_m^2 = \frac{(42-39.75)^2 + (43-39.75)^2 + (38-39.75)^2 + (36-39.75)^2}{4 - 1}, \text{ or}$$

$$s_m^2 = 10.92$$

$$t^* = \frac{\overline{X}_m - \overline{X}_b}{\sqrt{\frac{s_m^2}{n_m} + \frac{s_b^2}{n_b}}}$$, and for this example,

$$t^* = \frac{39.75 - 13.31}{\sqrt{\dfrac{10.92}{4} + \dfrac{13.43}{16}}}, \text{ or}$$

$$t^* = 13.99$$

Now, from Table 2-4

t_b = Table 2-4 with 15 degree of freedom, significance level = 0.01,

$t_b = 2.602$,

t_m = Table 2-4 with 3 degree of freedom, significance level = 0.01,

$t_m = 4.541$.

The weights are:

$$W_m = \frac{s_m^2}{n_m} = \frac{10.92}{4} = 2.7300,$$

and

$$W_b = \frac{s_b^2}{n_b} = \frac{13.43}{16} = 0.8394$$

Therefore,

$$t_c = \frac{W_b t_b + W_m t_m}{W_b + W_m}, \text{ and for this example,}$$

$$t_c = \frac{(0.8394 \times 2.602) + (2.7300 \times 4.541)}{(0.8394 + 2.7300)},$$

giving $t_c = 4.085$.

As t^* (=13.99) is larger than t_c (=4.085), the conclusion is that there has been a statistically significant increase in TOC level. In this particular example the procedure of §265.93(c)(2) concerning obtaining, splitting and analyzing additional samples would then be followed.

Owner or Operator Response to the Statistical Analysis

Student's t-Test Results for Upgradient Wells

A student's t-test for an upgradient well that shows a significant increase in the concentration or value of an indicator parameter (or decrease also in pH value) may mean that sources other than the facility may be affecting ground-water quality. If comparisons of the concentrations of indicator parameters for the upgradient wells show a significant increase (or also pH decrease), the owner or operator must submit this information in accordance with §265.94(a)(2)(ii) (see Section 2.5.3).

Possible conditions that could cause an indication of ground-water contamination in upgradient wells include:

- error in sampling and/or analysis of ground-water;
- actual contamination of ground water (e.g., due to a discharge, spill or other incidents upgradient of the facility);
- actual contamination due to a facility discharge and a mounding effect of contaminated ground-water beneath the facility; and
- actual contamination of ground water due to a facility discharge and a change in hydraulic gradient, so that the originally upgradient wells are now downgradient relative to the facility. This condition should be reflected by data on the ground-water surface elevations.

Student's t-Test Results for Downgradient Wells

A student's t-test for any downgradient well that shows a significant increase in the concentration or value of an indicator parameter (or decrease also for pH) signals possible ground-water contamination and is the first indication of a possible facility discharge. Section 265.93(c)(2) requires that if the comparisons for downgradient wells made under §265.93(b) show a significant increase (or also a pH decrease), the owner or operator must then immediately obtain additional ground-water samples from those downgradient wells where a significant difference was detected, split the samples in two, and obtain analyses of all additional samples to determine whether the significant difference was a result of human error. If the previous results are refuted and no significant change has occurred, the detection program can be resumed per the original schedule.

If the additional analyses performed under §265.93(c)(2) confirm the significant increase (or pH decrease), the owner or operator must provide written notice to the Regional Administrator - within seven days of the date of such confirmation - that the facility may be affecting ground-water quality. The written notice should include the relevant calculation(s) performed according to §265.93(b). The owner or operator must then develop and submit to the EPA Regional Administrator a ground-water quality assessment program plan within 15 days of the written notice (see Section 3).

2.5.3 Recordkeeping and Reporting

Recordkeeping

Owners or operators are advised to keep records of all professionally certified designs and analyses performed in accordance with the preceding parts of this section. These records should be maintained in an orderly fashion, possibly part of the sampling and analysis plan if appropriate, and be made available to Agency personnel during facility inspections. The outline in the Table of Contents may provide a convenient format for most facilities, but as mentioned in Section 1.3, Program Implementation, the Agency has decided not to prescribe a rigid format for the on-site documentation. Since lab reports, well logs, consultant reports and other components are not readily adjustable to a fixed format, it would be counter-productive to suggest one.

The detection monitoring system capability should be demonstrated first by showing the rationale for sampling points, second by defense of the frequency (whether minimum, additional or alternate), and third by discussion of the adequacy of the indicator parameters to assure detection. The system compliance with casing and sealing requirements may take the form of a geologist's certification of inspection. Lab reports should be clipped or inserted directly into the records in looseleaf.

Detection program records will serve as a history of whether the facility has affected ground-water quality of the underlying aquifer (i.e., through statistically significant changes in indicator parameter values). Section 265.94(a) requires that, unless the ground water is monitored to satisfy the requirements of §265.93(d)(4) (assessment program monitoring), the owner or operator must keep records of the analyses required in §265.92(c) and (d), the associated ground-water surface elevations required in §265.92(e) and evaluations in §265.93(b) until final closure of the facility, and, for disposal facilities, throughout the post-closure care period as well. Such records include:

- measurements of the ground-water surface elevation at each monitoring well for each sampling event;

- analytical results for:

  - drinking water suitability parameters;
  - ground-water quality parameters;
  - contamination indicator parameters; and

- calculated results for the contamination indicator parameter data:

  - arithmetic mean
  - variance
  - Student's t-test.

The records of these data should be organized in such a way as to clearly show: any relevant statistically significant difference(s), the exact location(s) and date(s) of any such significant difference(s), and a chronology of events of potential contamination according to well location since the start of ground-water monitoring at the facility. In addition, since changes in the ground-water conditions may occur very slowly, the values and concentrations of all the indicator parameters should be recorded so that any gradual changes over time and space are readily observable and can be studied. These records will be valuable in determining the significance of increases and decreases in indicator parameters. Since this information may help to identify the type and extent of any ground-water contamination, it could also aid in the successful implementation of a ground-water quality assessment program.

Reporting

As previously discussed, the owner or operator must submit a report identifying parameters listed in §265.92(b)(1) whose values exceed the maximum contaminant levels for those parameters of 40 CFR 265 listed in Appendix III (see Appendix C of this document). The report must be submitted within 15 days of the analysis, and separately identify the background well and downgradient wells, the parameter exceeding, and the concentration.

After the first year's sampling and establishment of background values for the indicator parameters of §265.92(b)(3) downgradient values statistically differing from background must be reported within 7 days. Upgradient values statistically differing must be reported annually, along with recommendations for revising the background values.

If the evaluation of ground-water surface elevations under §265.93(f) indicates a gradient change which affects the system capability, a description of the response to that evaluation, where applicable, must be reported. Reports of the above information are to be submitted to the Regional Administrator until final closure of the facility, and for disposal facilities, throughout the post-closure care period as well.

[Note: Annual reporting of ground-water monitoring information under §265.94 is due by March 1 of each year, along with the annual report under §265.75, or independently, if §265.75 is modified].

2.6 Waiver Demonstration

The waiver demonstration, as provided in §265.90(c), is a variance mechanism by which owners and operators design and defend any reduction in the monitoring programs required by Subpart F. The reader is referred to Section 1.2, above, for discussion of the rationale of waiver provisions. While the reduction or elimination applies to either or both the detection and assessment program, it is discussed in Section 2 of this manual because of the similarity of the approaches in detection monitoring and demonstrating a waiver. That is, similar hydrogeological investigative techniques (e.g., use of boreholes and remote geophysics) will likely be necessary for each.

On January 11, 1981 the regulations were amended, by addition of §265.90(e), to extend the waiver provisions to apply to neutralization surface impoundments. Those facilities shown to rapidly neutralize corrosive wastes, and to contain no wastes exhibiting other hazardous characteristics, are now eligible to waive the ground-water monitoring requirements. Owners and operators of such facilities must prepare a written demonstration showing that there is no potential for migration of hazardous wastes out of the facility. The demonstration would have to show, based on consideration of the corrosive wastes and the impoundment, that the corrosive wastes will be neutralized before they migrate out of the facility. The demonstration must be certified by a professional qualified to make this type of technical demonstration (e.g., a chemist), rather than necessarily by a geologist or geotechnical engineer (as required in §265.90(c)).

Under §265.90(c) a written demonstration of a low potential for ground-water contamination is necessary in order to substantiate a waiver. This demonstration must be based upon the site hydrogeology and certified by a qualified geologist or geotechnical engineer. The certifying geologist or geotechnical engineer should be present during any field testing so that he may supervise and gain first-hand knowledge of the site hydrogeology.

This discussion is intented to explain the criteria for a waiver demonstration under §265.90(c) to provide guidance in obtaining the necessary hydrologic data, and subsequently to guide readers in the preparation of the written demonstration.

Determining the potential for ground-water contamination involves an evaluation of the hydrogeologic factors in a water balance, characteristics of the unsaturated and saturated zones, and the pathway between the facility and water supply wells or surface water. The water balance determination is important because it will indicate the quantity of leachate that could be discharged by a facility. Evaluation of unsaturated and saturated zone characteristics will provide information in the rate at which contaminants will migrate and the extent to which contaminants may be attenuated in the subsurface environment. Determining the location and proximity of water supply wells and surface waters and the existence of an interconnection or pathway is necessary for establishing the likelihood of ground-water contaminants reaching and impacting these receptors.

The waiver demonstration requires a thorough evaluation of criteria for determining the potential for contamination of ground-water supplies and surface water. In order to protect human health and the environment, ground-water monitoring requirements are not to be waived for reasons such as:

- unsuitability of the uppermost aquifer for drinking water;
- expense of complying with ground-water monitoring requirements; and
- facility design.

The waiver mechanism allows varying degrees of deviation from the ground-water monitoring requirements. The lower the demonstrated potential for contaminant migration, the waiving of more requirements may be justified. For instance, if the unsaturated zone consists of a thick formation of very low hydraulic conductivity and the ground water moves at a slow rate, the potential for contaminant migration is low and may warrant a reduced frequency of sampling of ground-water monitoring wells. A complete waiver from the ground-water monitoring requirements would be very difficult to demonstrate since it must be established that there will be no potential for migration of hazardous waste or hazardous waste constituents through the uppermost and any interconnected aquifers to water supply wells or surface water without regard to time. The Regional Administrator can request, at any time, to examine the written waiver demonstration, prepared by the owner or operator, to evaluate the supportability of the waiver. Also, waiver demonstrations will be routinely examined as part of facility inspections. Appropriate data and investigatory techniques for a waiver demonstration are described below.

2.6.1 Determining Potential for Contaminant Migration from Facility to the Uppermost Aquifer

In order to establish the potential for migration of hazardous waste or hazardous waste constituents from the facility to the uppermost aquifer, the owner or operator is required to evaluate a site water balance and unsaturated zone characteristics. The following discussions explain these components.

Determining the Water Balance

The infiltration fraction of precipitation is the principal contributor to leachate generation from a hazardous waste management facility. Infiltration into cover material (if present) and any subsequent percolation down to the waste material, to the unsaturated zone, and eventually to ground water will be determined by surface conditions of the facility and by the hydrogeologic characteristics of the facility's location.

The water balance, as developed in the soil and water conservation literature, is based upon the relationship among precipitation, evapotranspiration, surface runoff and soil moisture storage. Precipitation represents that amount of water added. Evapotranspiration, the combined evaporation from plant and soil surfaces and tranpiration from plants, represents the transport of water from the earth back to the atmosphere, the reverse of precipitation. Surface runoff represents water which flows directly off the area of concern. Soil moisture storage represents water which can be held in the soil. Water balance calculations, employing the above parameters, can be solved to determine the percolation to ground water. Knowledge of the volume and placement of waste material can, further, provide an estimate of the potential amount of leachate which could be discharged from the facility. The water balance can be expressed as:

$P - R = I;$

$I - AET = Perc;$

where P = precipitation;

R = runoff;

I = infiltration;

AET = actual evapotranspiration; and

Perc = percolation.

If I minus AET is positive, over a given time interval, then soil moisture storage will increase. After the soil moisture storage reaches its maximum, any excess infiltration becomes percolation through the cover soil (if any) and waste materials, eventually reaching ground water. Therefore, significant percolation will occur during those time intervals when I exceeds AET and the soil moisture storage exceeds its maximum. For most humid areas, this will occur during the wet season. For dry areas, significant percolation may occur only in very short episodes if at all. For methods of determining the water balance, see Fenn, et al (1975) and Thornthwaite and Mather (1955, 1957).

The following discussion provides further information on the water balance factors and also provides methods of obtaining the needed data.

Precipitation

Precipitation data is tabulated in the form of mean monthly values for 30-year periods for each National Weather

Service station across the country. This information can be requested from the National Climatic Center, Federal Building, Asheville, NC 28801, 704/258-2850 (see Figure 2-16). Other possible sources for monthly precipitation data include State Departments of Agriculture, local universities, and associated technical publications. On-site field measurements should be used to validate regional data for the site; an onsite survey will be needed if suitable data is not available.

The owner or operator should obtain mean monthly precipitation values for the weather station closest in location and geographic characteristics to his facility (e.g., a coastal station often does not accurately reflect the precipitation characteristics of an inland location, despite close proximity). In the case where the station does not accurately reflect the precipitation at the facility site or the data is incomplete (e.g., missing records) or of questionable reliablility (e.g., discrepancies in values), the owner or operator should obtain more accurate data from alternate sources. Available on-site or nearby determinations are highly desirable. Consistent relationships may be entered into a calculated P-value. Once precipitation data has been obtained, the mean monthly values should be tabulated for each month and retained for later use in these calculations. Recorded anomalies should also be tabulated when significant and available.

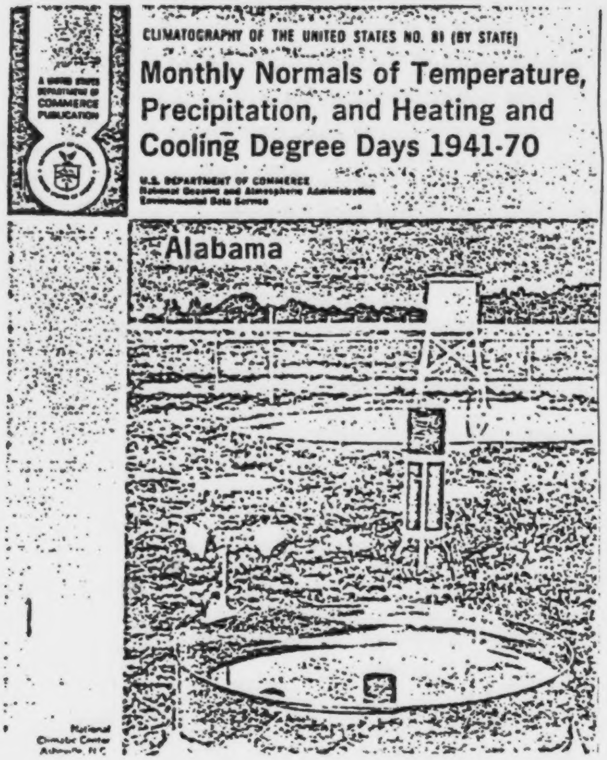
Evapotranspiration

Evapotranspiration is the amount of water returned to the atmosphere as vapor through the combined action of evaporation and transpiration. If, as is often the case, the overall amount of evaporation cannot reliably be measured separately from transpiration, the two effects are considered together as "evapotranspiration".

Several techniques are available for calculating potential evapotranspiration. Well-known methods include: Thornthwaite (1948), Blaney-Criddle (1962) and Penman (1948). Conversion from potential to actual evapotranspiration is generally performed using a soil moisture budget approach (e.g., Holmes and Robertson, 1959).

Evapotranspiration values obtained should be tabulated by month, as with the precipitation data. It should be noted that no completely successful technique for estimating evapotranspiration has been devised to date. Therefore, the above-listed methods should be evaluated for their applicability to site-specific conditions. Where soil temperatures, solar loading due to slope, ground cover, etc., or wind velocity and humidity may significantly affect AET, these should be separately introduced into the calculation.

Figure 2-16
Example of Monthly Precipitation Records



A UNITED STATES DEPARTMENT OF COMMERCE PUBLICATION

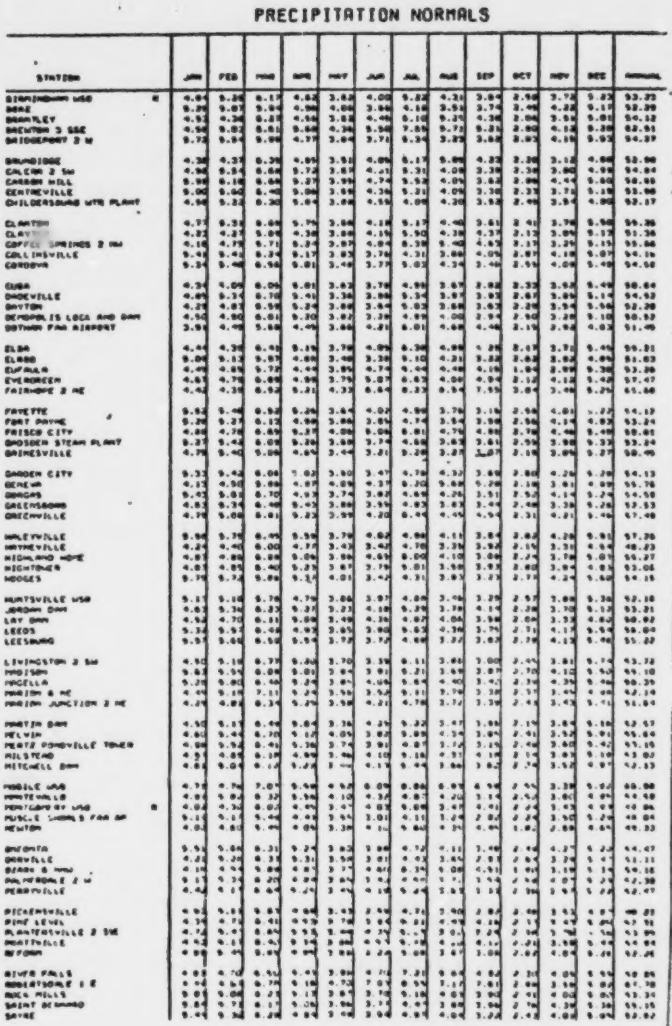
CLIMATOGRAPHY OF THE UNITED STATES NO. 81 (BY STATE)

Monthly Normals of Temperature, Precipitation, and Heating and Cooling Degree Days 1941-70

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
Environmental Data Service

Alabama

National Climatic Center
Asheville, N.C.



PRECIPITATION NORMALS

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Runoff

Runoff is the amount of incident precipitation that becomes overland flow before it has a chance to infiltrate. The amount of actual surface runoff varies with the intensity and duration of the storm, the antecedent soil moisture condition, the permeability and infiltration capacity of the soil, the slopes, and the amount and type of vegetation cover. Although it is difficult to account for all these factors in estimating runoff, most available methods account for at least some of the above-mentioned factors.

There are several methods for estimating the runoff fraction of incident precipitation. Although it will, in most cases, underestimate surface runoff, the "Rational Runoff" formula is presented here as one of the more convenient methods. The "mean monthly surface runoff" (R) can be calculated as follows:

$$R = P \times C_R;$$

where P = mean monthly precipitation; and

C_R = empirical runoff coefficient (see Chow, 1964).

The runoff coefficient C_R provides the means of estimating surface runoff quantities for given site conditions. The coefficients take into account a variety of vegetation types, soil types and slope steepness, and have been tabulated (e.g., by Chow, 1964). The owner or operator should match his site characteristics against those listed in the tables (e.g., Chow, 1964) and select the coefficient for the site characteristics which most nearly approximate his own site.

The owner or operator should tabulate the mean surface runoff values by month.

Infiltration

Infiltration is the amount of precipitation that enters the surface of the soil. It represents a source of moisture that may eventually percolate through the facility and unsaturated zone into the ground water.

Infiltration can be calculated using the values derived in the preceding discussions as follows:

$$I = P - R.$$

This calculation should be performed for each month unless anomalies indicate otherwise. A negative value for I indicates that the amount of infiltration is not sufficient to exceed soil moisture storage capacity (i.e., no percolation is likely to occur). A positive value for I indicates soil moisture storage recharge and potential percolation.

Percolation

Percolation is calculated as follows:

$$Perc = I - AET.$$

By determining the percolation rate, the area and depth of the waste, and waste/soil moisture storage capacity, the owner or operator can derive a rough estimate of potential leachate volume (see Fenn, et al, 1977, pp. 212-214 for further details).

Facility Site-specificity

The water balance method is a useful tool for evaluating the potential for contaminants to migrate through the unsaturated zone. However, it must be recognized that certain site-specific assumptions are necessary to tailor the method to a particular site. These assumptions are incorporated into the choice of precipitation data, and the choice of methods for determining evapotranspiration and surface runoff. In addition, conditions such as bare soil/lack of vegetation, irrigation (e.g., by land treatment), frozen ground and snow-melt must be accounted for where they affect the site (Fenn et. al., 1975).

The water balance method can be used to calculate infiltration at land treatment facilities. In this approach, the applied liquid waste and precipitation are volumetrically summed as the input, and infiltration is computed as the difference between this input and evapotranspiration. Applied liquid waste volumes can be determined from operating records. Precipitation volumes can usually be extrapolated from rainfall gaging stations in nearby areas. Monthly rainfall determinations are often suitable; however, in areas with highly variable precipitation, such as in Southwestern States, onsite measurements may be necessary.

Evapotranspiration from areas where land treatment is practiced can be determined by a number of methods (Cruff and Thompson, 1967; Blaney and Criddle, 1962; Lowry and Johnson, 1942; Penman, 1948; and Thornthwaite, 1948). These methods are generally based on different groupings of climatological parameters. For example, the Blaney-Criddle method depends primarily on temperature and percentage of daylight hours. In general the Penman and Thornthwaite methods are more applicable to humid areas, where the BlaneyCriddle method is more applicable to semiarid areas. Different values of evapotranspiration and consumptive use are usually obtained for different vegetation and soil conditions. Thus, the vegetation pattern must be known.

Sufficient field tests have been conducted in many areas so that evapotranspiration and consumptive use are well established. In some areas, data may have to be extrapolated from similar areas. Evapotranspiration rates will generally be needed on at least a monthly basis, and sometimes weekly.

In the water balance for land treatment, the infiltrating component is divided into two portions. A portion of this component is diverted into soil moisture storage. This soil moisture component will be gradually depleted by transpiration during periods of zero recharge. It should be noted that evapotranspiration calculations which continue to indicate evapotranspiration during depleted periods give distorted, unacceptable results. When the field capacity requirements have been satisfied the remaining portion will percolate to the zone of saturation.

The water balance method can also be used to calculate discharge from surface impoundments. Waste discharge and precipitation are volumetrically summed as the input, and discharge is calculated as the difference between input and evaporation. Storage changes in the impoundment must also be taken into account. Evaporation from free-water surfaces can be determined from measurements using land pans or floating pans (Harbeck et al, 1958; Kohler et al, 1955; Follansbee, 1933; and Rohwer, 1933). Monthly values will often suffice; however, in some cases weekly or daily values are necessary.

Factors such as salinity of waste liquid can affect the evaporation rate. In general, with increasing salinity the vapor pressure of water decreases, resulting in a lower evaporation rate. In considering evaporation from free-water surfaces from impoundments of different sizes, consideration should be given to edge effects. That is, evaporation rates depend on the characteristics of the surrounding land, for example, whether it is cultivated or undeveloped.

When applying the water balance to landfills, precipitation volumes must be obtained and the portion that infiltrates the landfill determined. This portion will first go into meeting the moisture storage requirements of the waste and cover material. For this reason the moisture content of the waste must be estimated. When the waste reaches field capacity percolation will result.

The results of water balance calculations do not represent absolute values of potential for contaminant migration. Instead, the resulting values will be used in concert with all other factors provided by the waiver demonstration in evaluating the relative potential for contamination.

Determining Unsaturated Zone Characteristics

The topsoil and materials of the unsaturated zone may have a significant but sometimes temporary capacity to remove a limited quantity of contaminants from downward-percolating waters. The extent of ground-water contamination due to waste percolation from the land surface depends strongly on the rate and volume of recharged water. In a semiarid or arid climate, contaminants may be retained above the water table in a nearly permanent fashion. On the other hand, in humid areas contaminants may be rapidly carried downward from the land surface to the water table. Generally, in a homogeneous porous media, percolating water will pass vertically through the unsaturated zone. However, in a heterogeneous, stratified material (e.g., most of the alluvial deposits of the western U.S.), percolating water may become perched above layers of low hydraulic conductivity. In this situation, lateral movement for substantial distances can occur above the water table.

The capacity for attentuation of many potential contaminants is greatly affected by the amount and characteristics of the geologic materials present in the unsaturated zone. This is especially true for the sorption capacity of many organic chemicals and trace elements. This limited capacity for removal of some contaminants is in sharp contrast to the almost unlimited ability of many unconsolidated materials to remove bacteriological contaminants. The existence of many documented case histories of ground-water contamination indicates that the unsaturated zone may often not provide complete protection. Problems can occur when attenuation capacity is exceeded due to high waste loadings.

Identify Geologic Materials

The owner or operator should begin to investigate the characteristics of the unsaturated zone by collecting available information about the geology underlying the facility area prior to any field testing. Background information will provide initial identification of materials, indicate areas where data is lacking, indicate which field tests should be performed, and later may serve to verify field data or indicate what further testing is needed.

Information abour reginal and site-specific geology should include:

- topography, surface relief;
- geologic structure, locations and patterns of major fractures, joints and solution cavities;
- characteristics, thicknesses and areal distribution of soils;

- thicknesses of formations, stratigraphy, lithology, and formation homogeneity and continuity; and

- hydraulic conductivity.

Some sources for this information are listed in Table 2.1. This information should be evaluated to determine existing descriptions of geologic materials in the facility area. Once data gaps have been identified, field techniques should be used for verification and to supply additional information on the identity of on-site geologic materials. For example, boreholes are one method of direct investigation of the subsurface, and are particularly necessary in support of direct methods. Formation samples collected from boreholes can provide data on the identity of geologic materials in the unsaturated zone and on the thicknesses of formations. Samples that have been collected from boreholes or preliminarily identified in the field should be sent to a qualified soils laboratory for identification confirmation and other appropriate tests.

Indirect geophysical techniques, such as geophysical logging, surface electrical resistivity and seismic surveys can provide augmentation to the information about site geologic materials. They are particularly useful in demonstrating continuity between direct sampling points.

Discussions of procedures, applicability, advantages and disadvantages of direct and indirect field methods of subsurface investigation are presented in Sections 2.2.1, 2.2.2 and 3.3.

Determining Physical Properties and Depth to Ground Water in the Unsaturated Zone

The hydraulic conductivity (K) of materials within the unsaturated zone is an important factor in determining contaminant pathways and the potential and/or time needed for contaminants to reach ground water. Low K values (e.g., 10^{-8} cm/sec) may be used in support of a waiver demonstration. Such values can be found in earth materials such as unfractured clays and shales. (Methods for determining K are presented in Section 3.2). When gathering data concerning K values, the owner or operator should evaluate and document, at least, the following:

- variations in K areally and with depth; and

- continuity and thicknesses of materials with given K values.

Thick unsaturated zones (e.g., 100 meters), in conjunction with low K values, can be supportive of a waiver demonstration.

Thickness data should be established through reliable methods (e.g., borehole logging). Such information should not be obtained by boring through the waste management area, as this could provide a direct conduit for hazardous wastes to reach the ground water.

Depth to ground water should be accurately determined within the facility area (see Sections 2.2.1 and 2.2.2 concerning historical records, piezometers and water table wells, and water-level measurement techniques). Water level elevation data should be used to construct flow nets which indicate hydraulic gradients and ground-water flow directions (see Section 2.2.2 for a discussion on flow net construction). Water elevation and unsaturated zone thickness data are needed to determine the distance contaminants must travel to reach the uppermost aquifer.

Evaluating Attenuation Capabilities of the Unsaturated Zone (adapted from Todd, et al, 1976)

Various factors and processes affect the mobility of contaminants moving through the unsaturated zone. Close examination and documentation of the effects of these factors and processes may lend credence to a waiver demonstration.

Contaminant attenuation in the subsurface commonly occurs due to the following processes: dilution, filtration, sorption, buffering, precipitation, oxidation and reduction, volatilization, biological degradation and assimilation.

Dilution

One of the mechanisms of attenuation frequently mentioned in the literature is dilution. The obvious limitations for use of dilution to substantiate a waiver preclude its use as a primary basis at landfills and surface impoundments. Continuous sources of contaminants in laminar flow situations cannot be shown to be so dilute that they meet the "no or low probability" criterion for a waiver. Dilution as discussed in this section is of course a factor in attenuation. It may have applicability in waiver demonstrations in unusual cases unforeseen by the Agency, and of course, it is a necessary consideration in design of detection programs. Therefore, it is included here primarily for sake of completeness.

Dilution above the water table can be substantial in humid areas and almost nonexistent in arid areas. Sources of water for dilution include precipitation, seepage from streams, lakes and canals, and artificial recharge. The quality of water from each source of recharge should be estimated if, in the judgement of the geologist or geotechnical engineer, it might be a significant factor. A comparison of the respective quantities of water and constituent concentrations in a waste discharge at the land surface can indicate the extent of subsequent dilution of contaminants.

An example is presented in the following discussion. Assume an agricultural area in the West where irrigation is practiced in the dry summer months and rainfall occurs in the wet winter months. Return flow over the area averages 18 inches per year and the salinity of this water is 300 parts per million (ppm). Rainfall is 12 inches per year and its salinity is 10 ppm. Consideration of the water balance analysis at the land surface indicates that 9 of the 12 inches of rainfall percolates to the water table. The maximum subsequent dilution, presuming thorough mixing, can be calculated by the equation:

$$AV_A + BV_B = C;$$

where V_A and V_B are respective percentages of water from return flow and precipitation. A, B, and C are the respective salinities of the return flow, precipitation, and the mixture of the two. In this example:

$$C = 300(18/27) + 10(9/27)$$

$$C = 200 + 3 = 203 \text{ ppm.}$$

This dilution theoretically reduced the salinity by about one-third of the original value. This simple concept can be expanded to encompass dilution from a number of sources of contamination. The resultant concentrations of contaminants of concern is reduced. Technically, attenuation has occurred. As noted, however, the contaminants are no less likely to enter ground water, and no support is foreseen for waiver demonstration.

Filtration

Filtration can remove many of the suspended materials that would be of concern. However, this process is generally not effective for dissolved and other liquid phase materials except as precipitates form due to chemical reactions. Since most leachate of concern is not filterable except as precipitants too complicated to predict, no guidance is available from the Agency on filtration as a factor.

Sorption

Sorption is probably one of the most effective but most unpredictable processes for attenuating ground-water contaminants. Clays, metallic oxides and hydroxides, and organic matter can all be suitable materials for sorption of various contaminants. Many contaminants can be sorbed and removed to some extent under favorable conditions. Under other circumstances, however, the contaminants can move freely through the porous media. The pH and oxidation potential often govern the extent of sorption for specific constituents. The sorption process depends on the type of contaminant and the physical and chemical properties of both solution and the containing materials.

When a contaminant in ionic form is sorbed, some other changes must occur to compensate for loss of the ion from solution. In ion-exchange processes, a different ion is released by the solid to the water. However, this release is not required if the contaminants are sorbed or electrically neutral, such as most organics and neutral complexes of various metals.

The sorptive capacity can be estimated based on the density, clay content, and cation exchange capacity of the soil and geologic materials above the water table. Values for these parameters can be calculated from available data in soils and ground-water reports on the area of interest. In exceptional cases, these parameters can be determined from detailed onsite measurements. For calculation purposes, the thickness of the unsaturated zone is known or determined from water level data. For simplicity, the vertical path of contaminated water from the land surface beneath the waste management area to the water table can be assumed to be the distance traveled.

As an example, assume the average density of materials in the unsaturated zone is 1.6 grams per cubic centimeter, the clay content is 20 percent by weight, and the clay has a cation exchange capacity of 70 milliequivalents per 100 grams. Each gram of clay will have the ability to remove 0.70 milliequivalents of the constituent of interest. For example, for potassium (equivalent weight of 39), each gram of clay will have the ability to remove 27.3 (0.70x39) milligrams of potassium from the percolated waste water. Each gram of solid material will have the ability to remove 5.5 (0.20x27.3) milligrams of potassium from the percolated waste water. With a density of soil of 1.6 grams per cubic centimeter, one acre-foot (1.2335×10^9 cubic centimeters) of soil would contain 1.97×10^9 grams of solid material. This soil could sorb 23,900 pounds of potassium. For an unsaturated zone 50 feet thick, one acre of the unsaturated zone could sorb over one million pounds of potassium, presuming uniform applications in adsorbable doses, and no interference from other constituents.

To determine the actual extent of adsorption, laboratory tests can be performed utilizing soils and geologic materials typical of the waste management site. The actual waste discharge can be used or a similar synthetic solution prepared. Hajek (1969) summarizes laboratory procedures for such tests.

It should be noted that the percolating fluids may subsequently remobilize species that have been sorbed. The sorptive capacity of soils and geologic materials is finite for most inorganic substances which cannot be biodegraded. However, for substances which are biodegradable, such as many bacteriological constituents and nitrogen, the sorptive capacity may be renewed indefinitely.

Buffering

The pH is a critical factor in many reactions involving contaminants. Buffering is the resistance to a pH change of the soil solution. The basis of buffer capacity lies in the adsorbed cations on the exchange complex of the soil. The higher the exchange capacity, the greater will be the buffer capacity. The portion of the cation exchange capacity occupied by exchangeable bases is termed base saturation. There is a correlation between base saturation and pH, with higher base saturation for higher pH. The degree of buffering is lowest at the extremes of base saturation, and highest at intermediate base saturation values.

The extent of buffering in most cases will be relatively unimportant if the pH of the waste discharge is between 6 and 9. These pH values correspond to those commonly found in natural ground water. Wastes with a pH in this range will generally be buffered to an extent that the percolating waste water will present no unusual problem. Consideration of buffering is thus of foremost importance in cases of disposal of very acidic or basic wastes. Detailed considerations are presented in Buckman and Brady (1969).

Chemical Precipitation

It is theoretically possible to precipitate almost any dissolved species from solution. However, in soil-groundwater systems, the necessary species often are not present in sufficient quantities to precipitate potential contaminants. Certain constituents are normally present and available for reaction in most ground water, soil, and geologic materials. Calcium, magnesium, sodium, potassium, bicarbonate, sulfate, chloride, and silica are usually the major species in ground water. Iron, aluminum, nitrogen, and carbonate, in addition to the previous constituents, may be found in soil and geologic materials.

Due to the extreme complexity, this manual is not an appropriate vehicle for guidance on chemical precipitation. However, references such as Hem (1970), Stumm and Morgan

(1970), Faust and Hunter (1967), and Gould (1967), detail thermodynamic calculations which may be used to evaluate this phenomenon. In many field situations data are commonly lacking on some parameters of importance, thus judgement is often necessary.

Oxidation and Reduction

The oxidation of organic matter in the topsoil is one of the most important contaminant attenuation mechanisms. Oxidation and reduction reactions often work in conjunction with other mechanisms for contaminant attenuation. Besides those reactions causing precipitation, reducing conditions can also theoretically cause the formation of native elements which are quite insoluble. Sulfides can react with certain metals to produce highly insoluble precipitates, such as sulfides of arsenic, cadmium, mercury, and silver.

Volatilization

Volatilization and release as a gas can be effective for attenuating some ground-water contamination. For example, mercury in solution can be volatilized in anaerobic environments or by reactions with dissolved humic acids. Several organic compounds of arsenic are volatile, and the escape of arsenic as a gas has been demonstrated for both aerobic and anaerobic soils. Selenium may be subject to volatilization because of its chemical similarity to sulfur. The microbial reduction of nitrate to gaseous forms of nitrogen is well documented. No quantitative procedure is proposed to evaluate the extent of this phenomenon. It is important to be aware of the contaminants that may be affected.

Biological Degradation and Assimilation

These processes are very important in the removal of organic and biologic contaminants. Many organic chemicals can be attenuated or removed by biological activity in the unsaturated zone. Nitrate, arsenic, cyanide, mercury, and selenium are likely candidates for biologic fixation or volatilization.

2.6.2 Determining Potential For Contaminant Migration Through Uppermost Aquifer to Water Supply Wells or Surface Water

It is essential in protecting human health and the environment to establish the potential for contaminants to migrate through the uppermost aquifer, and any interconnected aquifers, to water supply wells or surface water. The Agency recognizes the potential interconnections between aquifers at different depths. The potential for contamination of relatively deeper aquifers may be low if, for example, the two aquifers are separated by thick strata with low K value and no effective hydrologic interconnections exist (e.g., fractures; abandoned, poorly sealed wells). Characterizing the saturated zone by determining the geologic materials, physical properties and velocity of ground-water flow will indicate the potential rate and extent of contaminant migration in the saturated zone. Continuity of the hydraulic pathway from the facility to wells and surface water is of particular concern. The distances, the ground-water flow velocity and the flow direction are factors influencing contaminant entry into wells and the surface water environment. The regulation does not introduce time as a criterion; low probability in terms of geologic time includes millenia.

Determining Saturated Zone Characteristics

Identify Geologic Materials

The geologic materials of the saturated zone are identified by the same methods as previously described for the unsaturated zone.

Determining Physical Properties and Rate of Ground-Water Flow in the Saturated Zone

Field determination of K values within the saturated zone is needed to identify probable contaminant pathways (see Section 3.2 for methods of determining K). K can also be determined in the laboratory and estimated from values given in the literature for comparison to to field-obtained values. Hydraulic conductivity data along with information on porosity and hydraulic gradient can be used to compute ground-water flow rates (see Section 3.2). Tracer techniques can also be used to compute flow rates (see Section 3.2). Flow rates should be determined in appropriate aquifer flow zones in order to indicate directions of potential contaminant migration and to calculate the time it would take contaminants to reach any nearby water supply wells and/or surface waters. This process should include flow net analysis as described in the previous discussion of the unsaturated zone and Section 2.2.2.

Computer simulation and prediction models use a set of mathematical equations that attempt to describe and quantify the physical processes in an aquifer. These models can also be used to estimate ground-water flow rate. In order to determine where and when a ground-water flow model can be applied, it is necessary to have a detailed understanding of the aquifer's physical processes and the corresponding mathematical model. Not all simulation models are appropriate for all ground-water systems, and not all aquifers are amenable to or necessarily require such modeling. For instance, those aquifers involving a small area or a low level of hydrogeologic complexity may have the most efficient solution to ground-water flow rate via flow net analysis or analytical methods, such as application of the Darcy-based equation (see Section 3.2). A qualified person, such as the geologist or geotechnical engineer required to certify the waiver demonstration, can provide the expertise to judge the necessity of a modeling study, the appropriateness of the model selected, the need for any modifications to the model and accurate interpretation of the results.

Hydrogeological data which should be considered for use of a predictive ground-water model are listed in Table 2-5. General sources of data for ground-water flow modeling include:

- geologic and hydrogeologic reports and maps;

- well log data;

- water level measurements; and
- pumping test data.

The Holcomb Research Institute at Butler University, Indianapolis, Indiana maintains a computerized clearinghouse for ground-water models that can provide model users with an annotated list of models. Additional information on groundwater models is available from the U.S. Geological Survey, modeling researchers, and the technical literature.

Evaluating Attenuation of Contaminants in the Saturated Zone (adapted from Todd, et al, 1976)

Many of the attenuation processes which occur in the unsaturated zone can also occur below the water table, but in a modified manner. For example, the lower oxygen content below the water table reduces the possibility of oxidation of organic matter even when mixing does occur. Some contaminants may be more mobile in the reduced state. Reducing conditions are favorable, however, in some cases for contaminant removal from water (e.g., nitrate). Another major consideration is that organic matter, common in the topsoil, is virtually absent in many types of geologic materials comprising the aquifer. This would ordinarily decrease the extent of sorption as well as reactions such as denitrification. In addition, certain geologic materials, such as granite and limestone, may lack many of the common substrates for sorption. The dilution process below the water table differs greatly from that operative in the unsaturated zone.

Processes Other Than Dilution

The attenuation processes do not generally have to be considered in detail if the waiver demonstration is based upon a low potential for any infiltration or leachate to reach the saturated zone. In cases where the demonstration

Table 2-5

Data Requirements to be Considered for a Predictive Ground-Water Flow Model

Physical Framework

- Hydrogeologic map showing areal extent, boundaries, and boundary conditions of all aquifers
- Topographic map showing surface-water bodies
- Water-table, bedrock-configuration, and saturated-thickness maps
- Transmissivity map showing aquifer and boundaries
- Transmissivity and specific storage map of confining bed
- Map showing variation in storage coefficient of aquifer
- Relation of saturated thickness to transmissivity
- Relation of stream and aquifer (hydraulic connection)

Stresses on System

- Type and extent of recharge areas (irrigated areas, recharge basins, recharge wells, etc.)
- Surface-water diversions
- Ground-water pumpage (distributed in time and space)
- Stream flow (distributed in time and space)
- Precipitation

depends on saturated zone attenuation, detailed consideration of these processes is necessary. Filtration and sorption were treated in the unsaturated zone discussion. In saturated flow, contaminant movement is generally horizontal and, instead of utilizing a thickness of unsaturated zone beneath a waste management site, a volume of the aquifer will indicate the maximum attainable dilution. Generally, this will correspond to the projected, aggregate pore space volume and location of a discharged waste plume at a specific time. This volume can be estimated by utilizing flow net analysis to determine the vertical and horizontal direction of groundwater movement from beneath the waste management site. Specific distances from the waste discharge site, such as 100 feet, 500 feet, and 1000 feet, can be chosen and volumes of materials calculated for each.

Laminar flow and other ground-water phenomena result in incomplete mixing within the maximum potential mixing volume. Consideration must also be given to contaminants which do not readily mix with ground water (e.g., contaminants which migrate along the top of the water table and those which migrate along the bottom of the aquifer).

Buffering can be handled as discussed for the unsaturated zone. Generally, this is not of great concern unless extremely acidic or alkaline wastes are discharged directly to the saturated zone. Chemical precipitation can be handled as described for the unsaturated zone, but evapotranspiration is not a factor in concentrating solutions. In addition, the materials are continuously saturated below the water table and are usually not exposed to drying. Oxidation and reduction can be handled as for the unsaturated zone. However, in the saturated case, oxidation is generally less important and reduction is more important than in the unsaturated zone.

Dilution and Related Factors

Once percolating wastes reach the saturated zone, in most dynamic ground-water systems there will be some physical attenuation of contaminant concentrations with distance from the intersection with the water table. The attenuation occurring in most cases is determined by the following factors:

- the volume of a waste discharge reaching the water table;
- the waste loading (i.e., the mass per unit area of contaminant reaching the water table);
- areal hydraulic head distribution, as indicated by water-level elevation contour maps;
- transmissivity of aquifer materials;

- vertical hydraulic head gradients and vertical hydraulic conductivities through confining beds which are present;

- quantity and quality of native ground water available for mixing;

- quantity of recharge reaching the water table from other sources at the land surface; and

- chemical characteristics of recharge reaching the water table from other sources.

The first two factors determine the concentration of contaminants reaching the water table. The next several factors, along with hydraulic conductivity, determine the direction and magnitude of ground-water flow in the area and the quality of native ground water with which the discharged waste will mix. The last two factors determine the effect of recharge from other sources on contaminant concentration.

A first approximation of dilution can be obtained by assuming that the waste discharge enters a certain part of the aquifer; for example, the upper 10 feet, 50 feet, or 100 feet, over a certain area. Knowledge of the extent of ground-water contamination in historical situations in the area or a comparable area can be used to make this evalulation. Secondly, water reaching the water table from other sources of recharge and ground-water inflow from nearby areas usually tends to dilute the waste discharge. The dilution can be calculated if the volume and quality of the various sources of water are known. Conservative constituents, such as chloride, can be used for a first approximation of dilution. In most cases, the contaminant of interest will be less mobile and thus occupy a smaller plume than a mobile constituent such as chloride. Ground-water outflow tends to carry contaminants away from the waste management site.

Water level elevation maps and flow nets can be used to consider whether the waste discharge is in an area of converging or diverging ground-water flow, which affects dilution. Vertical head gradients indicate whether wastes could move to deeper levels of the aquifer or whether deeper aquifer water could move up and dilute the wastes. Both cases tend to accentuate mixing or dilution. Aquifer transmisivity can be used to calculate ground-water flow rates into and out of an area. The quality of sources other than the waste discharge and native ground water will obviously affect dilution as the lower concentration waters will exert relatively more dilution. The foregoing factors can be integrated into a mass balance analysis, both for the waste discharge and for the individual contaminants.

Wells affect dilution in several ways:

- Gravel packs or perforations if improperly designed can act to short-circuit confining beds and allow vertical movement of contaminants near the well.
- Well pumping can drastically alter flow patterns, both horizontally and vertically.
- Well pumping can remove contaminants from ground water and expose them to subsequent loss at the land surface or in the topsoil, by processes such as volatilization, crop uptake, and precipitation.

Most of the above-described factors are significant for all types of contaminants that reach the water table, whether they are inorganic chemical, physical, organic chemical, or bacteriological. In some cases, certain factors do not attenuate the contaminant, but rather redirect it. An example is the development of a large depression cone in an agricultural area, whereby contaminants are drawn into the area from many directions but are effectively prohibited from leaving by the depression.

Plumes or zones of contaminated ground water may behave as a slow moving viscous mass, but they may also be quite erratic, especially where influenced by recharge and/or well pumping.

Evaluation of contaminant attenuation mechanisms in the saturated zone requires a considerable knowledge of fluid dynamics, geochemistry, and hydrogeologic judgement. Such an evaluation is essential in order to adequately substantiate a waiver demonstration. Eminently qualified professionals known for their hydrogeologic judgement combined with experience gained from case histories are recommended for performing this task.

Determining Proximity of Facility to Water Supply Wells or Surface Water

The distance from the facility to water supply wells and surface water has a bearing on how contaminants reach receptors. As potential transmitters of contaminanted water, wells and surface water can expose these contaminants to the surface environment. All types of water supply wells and surface waters must be identified within a reasonable distance of the facility. Wells used for drinking, irrigation or any other purposes should be located and classified, and the type of usage should be noted. Pumping wells are of particular concern since they will accelerate the migration of any contaminants present in the water, and increase the likelihood that contaminants will reach receptors at the surface. Surface waters, including lakes, ponds, rivers, streams, wetlands (swamps, marshes, bogs), springs and salt-water bodies should also be identified.

When determining the effect of the proximity of the facility to these water supply wells and surface waters, a reasonable area should be considered. Many site-specific factors affect the size that a reasonable area should be, including:

- watershed or drainage basin boundaries;
- saturated zone characteristics (e.g., fractures, solution cavities, attenuating properties);
- direction of ground water flow; and
- rate of ground water flow.

A situation in which the attenuating capacity of the saturated zone is high and the rate of ground water flow is low, may warrant a lesser area for consideration. In some situations, (e.g., when the aquifer underlying the facility flows into a river located several miles from the facility), the area considered should include the river in order to identify this major discharge point. Another factor which might affect the size of the area for consideration is the number of wells and surface water bodies present in the region of the facility.

Sources of information which can provide the location of nearby water supply wells and surface waters include:

Existing Maps. Topographic and hydrogeologic maps have been prepared for many areas of the United States. Each map is drawn for a certain watershed or geologic region. Among other things, these maps show the location of wells and surface waters. Topographic and hydrogeologic maps may be obtained from the United States Geological Survey, State Geological Surveys, River Basin Commissions, and some universities. Other Federal and State agencies identified in Table 2-1 may also have these maps.

Prepared Map of the Area. A map of the area around the facility which indicates the location of water supply wells and surface waters can be prepared from review of the existing maps and other information sources previously described. The map should cover at least the area of the drainage basin(s) which could be affected by the facility. The map should include all water supply wells and surface waters currently located within the area being considered. The map should be comprehensive and current.

Other sources of information should be consulted to verify and supplement the information about the location of wells and surface waters, especially if existing maps are old or not available. The other information sources include local town engineers, state well-drilling records and published reports/ surveys. Drilling records and reports might be obtained from State Departments of Environmental Protection, State Geological Surveys or Public Health Departments.

If the owner or operator cannot otherwise document completeness, the map should be verified by performing a field survey. Depending upon the geology and property ownership in the area, the following tasks might be included in the field survey:

- contact other property owners to learn if any new wells have been drilled (or old ones overlooked by the previous research) and inquire about surface waters present on their property;

- drive/walk through the area (where permitted) to spot check portions of the map; and

- check state/locality files where drilling or extracting is regulated; consult local water-well contractors.

2.6.3 Documentation

Section 265.90(c) waiver demonstrations must be in writing, must be certified by a qualified geologist or geotechnical engineer, and must be kept at the facility; Section 265.90(e) waiver demonstrations must be certified by an appropriately qualified professional (e.g., a chemist) verifying the occurrence of the documented neutralization reaction(s). During interim status, the written waiver demonstration must be made available to the Regional Administrator upon his request.

The format of the waiver demonstration under §265.90(c) should correspond to the requirements of the regulation by documenting the evaluations of the water balance, unsaturated and saturated zone characteristics, and the facility's proximity to water supply wells or surface waters, upon which the contaminant migration potentials are estimated. The methods used to obtain these hydrogeologic data should also be included in the demonstration. Supplementary information should include:

- water balance calculation and how all values were obtained;

- the investigatory methods and how data were evaluated in determining the unsaturated and saturated zone characteristics; and

- the site-specific map and descriptions of field surveys used to determine the proximity of the facility to water supply wells and surface water.

In addition to the final written waiver demonstration, under §265.90(c) or (e), reproduceable copies of all supporting information (e.g., reports, records of field investigations and calculations) must be kept at the facility so that the demonstration is soundly documented at all times.

3.0 Assessment Program and Description

The ground-water quality assessment program must be capable of determining presence, concentrations, rate and extent of migration of hazardous waste or hazardous waste constituents in the ground water coming from a discharging facility. The owner or operator is responsible for preparing and implementing an assessment plan under §265.93(d) when there are significant indicator parameter changes in downgradient wells. (See Section 1.3 for a discussion of the level of detail for assessment plans.)

The detection program was designed as a screening mechanism in the determination of whether hazardous waste or hazardous waste constituents have entered the ground water from facility discharges. The data-evaluation procedures, including the Student's t-test, specified in §265.93(b) were chosen to make such determinations. In some cases the owner or operator may believe that the Student's t-test does not provide a reliable indication of whether hazardous waste or hazardous waste constituents have entered ground water. (For example, he may be able to demonstrate that the indicator parameter data collected at his facility violate the assumptions of the Student's t-test.) An owner or operator who believes that is the case may, in the first phase of his assessment program, attempt to show that the specified procedures are not appropriate for the facility. The owner or operator must document why he believes the specified procedures are inappropriate in his assessment plan and in the first assessment report submitted to the Agency. As part of this documentation the owner or operator should also submit the analytical results for the parameters establishing ground-water quality, listed in §265.92(b)(2).

It is also possible that the data collected might not properly reflect the actual quality of the ground water. This would most likely result from sampling or testing errors (e.g., sample contamination; poorly standardized instrumentation, etc.). If this is suspected of being the case, the owner or operator may, as a first step in his assessment program, conduct additional sampling and testing. In so doing, he must identify why he believes the original data to be faulty and what steps are being taken to prevent a reoccurrence.

If the detection program indicates that the facility is significantly affecting ground-water quality (see statistical analysis discussion; Section 2.5.2), a sequential response procedure must be followed. This procedure requires the owner or operator to respond to possible ground-water contamination according to the following sequence:

- Confirm sampling/analytical results by taking additional (split) samples (§265.93(c)(2));
- Notify the Regional Administrator within 7 days of confirmation that the facility may be affecting ground-water quality (§265.93(d)(1));
- Submit a specific plan for a ground-water quality assessment program to the Regional Administrator within 15 days of the above notification (§265.93(d)(2)), including the following:
    - ° A description of the procedures that the owner or operator will use to track the rate and extent of migration of hazardous waste or hazardous waste constituents.
    - ° (Optional) an explanation of the procedures the owner or operator will use to demonstrate that the results of the indicator monitoring did not provide reliable evidence that hazardous waste or hazardous waste constituents have entered ground water and an explanation, where possible, of more appropriate procedures for evaluating the data.
    - ° (Optional) the raw data collected in the indicator monitoring program, a general explanation of why the owner or operator believes the results do not indicate the presence of hazardous waste or hazardous waste constituents in ground water, and a request for assistance from the RA.
- Implement the assessment plan as soon as technically feasible (§§265.93(d)(4) and (5));
- Submit an assessment report to the Regional Administrator within 15 days of the first determination (§265.93(d)(5));
- Follow-on actions:
    - ° If the assessment indicates that ground water is being contaminated, continue the ground-water quality assessments on a quarterly basis until final closure of the facility (§265.93(d)(7)(i)). If contamination is first detected during post-closure, only one assessment is required (§265.93(d)(7)(ii)).

- If the assessment indicates no ground-water contamination, the detection program may be reinstated and the Regional Administrator must be so notified (§265.93(d)(6));

If the assessment indicates no ground-water contamination and the owner or operator believes that some set of detection monitoring procedures other than those specified in the regulations is appropriate, a demonstration of this may be presented to the Regional Administrator. Those owners or operators choosing to challenge the appropriateness of the Student's t-test are encouraged to suggest an alternate method of comparison and submit the rationale by which the method was selected. At a minimum the owner or operator should submit to the Regional Administrator the raw data from each well, each replicate, each parameter (including the ground-water quality data (§265.92(b)(2)), and each sampling event.

Challenging the appropriateness of the Student's t-test will not be considered just cause for delay in completing a necessary assessment plan. Similarly, an assessment program's implementation including identification of subsequent action in the event contamination is confirmed, cannot be delayed due to a challenge of the appropriateness of the Student's t-test.

The plan for the assessment program must be certified by a qualified geologist or geotechnical engineer who should serve the lead role in implementing the plan. The plan must specify:

- the number, location, and depth of wells;
- any geophysical techniques to be employed;
- sampling and analytical methods for those hazardous wastes or hazardous waste constituents in the facility;
- evaluation procedures, including any use of previously gathered ground-water quality information; and
- a schedule of implementation.

The plan must be based upon site-specific conditions to ensure adequate assessment in the event that ground-water is being contaminated. Guidance for determining the appropriate number, location and depth of wells is provided in the examples given later in this Section and in Sections 2.2.3 and 2.2.4. Sampling and analytical methods for determining the concentration of hazardous waste and hazardous waste constituents are discussed in Section 3.4. The evaluation procedures include use of any previously gathered ground-water quality information (e.g., data collected from the detection program). Data evaluation procedures can also be used to indicate that ground-water quality is being affected by a source other than the facility.

The first ground-water quality assessment must be performed as soon as technically feasible since a discharge to ground water may be presenting a serious risk to human health and the environment. If the evaluation of the results of the assessment indicates no ground-water contamination, the owner or operator may reinstate the detection program. The Regional Administrator must be notified of this program change so he will be aware of which program is in progress and which facilities are introducing hazardous waste or hazardous waste contituents to ground water. If the assessment shows that hazardous waste from the facility has entered the ground water, assessments must be continued on a quarterly basis. Any assessment which is initiated prior to facility closure must be completed and reported to the Regional Administrator.

The assessment program plan and implementation are required if the detection program has shown that the facility may be affecting ground-water quality. However, the owner or operator may have chosen to use an alternate program (see §265.90(d)), rather than the detection program, because he assumed or knew that the detection program would show that the facility is affecting ground-water quality. In this case the alternate program, which is essentially equivalent to the assessment program, must be employed and the owner or operator was required to prepare and implement the plan by November 19, 1981 in lieu of the detection program.

3.1 Determining Whether Hazardous Waste or Hazardous Waste Constituents Have Entered the Ground Water

Determining the actual presence of hazardous waste or hazardous waste constituents in ground water due to a facility discharge is a first necessary step after detecting via the Student's t-test a significant result for an indicator parameter. This determination should include, at a minimum, sampling of those existing monitoring wells exhibiting the change in indicators. It should reasonably include all wells likely to be in the flow path. These samples should be analyzed for all hazardous waste or hazardous waste constituents managed by the facility. The data comparisons in the assessment program are not necessarily restricted to the Student's t-test.

If the absence of hazardous waste or hazardous waste constituents is demonstrated, the owner or operator may wish to challenge the use of the statistical procedures required in the detection program. Such a challenge should include an explanation, using indicator parameter data collected for detection monitoring, of why the prescribed statistical procedures are not appropriate for his facility. For example, he may contend that the background data vary from a normal distribution to such an extent as to violate the assumptions of the Student's t-test. The owner or operator may submit alternate data-evaluation procedures (e.g., Mann-Whitney test for non-normally distributed data) with a rationale for their use. If the Student's t-test is challenged and if alternate procedures are suggested, the owner or operator should submit to the Regional Administrator the raw data from each well as discussed in Section 3.0.

3.2 Determining Rate of Contaminant Migration

Rate is primarily influenced by the hydraulic conductivity (K) of the medium; the porosity (n) of the medium; and the hydraulic gradient (i), a ratio of the difference in hydraulic head and the horizontal distance between two points. This discussion assumes that contaminants migrate at the same rate as ground water. If the owner or operator contends that the contaminant is migrating at a slower or faster rate than the ground water, methods capable of quantifying such a rate must be employed. The selected method(s) should be best suited to the specific conditions at the facility site.

Methods for determining rate are either theoretical, such as techniques dependent on use of a Darcy-based equation, or they are empirical such as techniques employing tracers.

3.2.1 Use of Darcy-Based Equation

The rate at which contaminants from a facility may migrate in the ground water can be calculated through the solution of a modified form of the Darcy equation:

$\bar{v} = \frac{-Ki}{n}$; where $\bar{v}$ is the average linear velocity ground water, K is the hydraulic conductivity of the medium, i is the hydraulic gradient, and n is the porosity of the medium.

In determining $\bar{v}$, it is important to realize and account for factors which contribute to variabilities in K, i, and n. Hydraulic conductivity will often vary with the direction of measurement (e.g., horizontal K is often greater than vertical K in unfractured, stratified earth materials). In ground-water monitoring, it is imperative to determine the flow zone(s) with high K values because it is within these zones that the rate of contaminant flow will likely be the greatest. These flow patterns can greatly affect patterns of dilution and other attenuation factors. Hydraulic gradient between the source of contamination and the detection point (e.g., well) can be affected by land use as well as hydrogeologic causes.

Seasonal fluctuations of water levels may alter the gradient. Caution should be given to determining gradient in situations where there are perched water bodies, since comparison of water levels from perched aquifers, whose retarding formations are at different depths, will result in an invalid gradient calculation. Also, gradient determination (as well as velocity) can be influenced by nearby constant or periodic ground-water supply pumping or clogged wells. Such influences should be accounted for by the owner or operator when conducting an assessment.

The hydraulic gradient (i) is the change in hydraulic head (h) over a given distance (i.e., the vertical difference in water level elevation (h_1-h_2) of two wells separated by a horizontal distance (l) in the direction of maximum slope). For example, the water level in Well A is five feet above mean sea level and the level in Well B, 100 feet away and on the same flowline, is four feet above mean sea level. The maximum hydraulic gradient in this case is computed as follows:

$$\frac{h_1 - h_2}{l} = \frac{5 - 4}{100} = \frac{1}{100} = 0.01.$$

This means that for every 100 feet horizontal distance, the water level drops 1 foot.

An important procedure in most ground water investigations is to identify the gradient over a specific area. The groundwater flow net shown in Figure 2-3, can be used to illustrate hydraulic gradient. Lines of equal "head" (equipotential lines) are used to define slope and perpendicular flowlines show the direction of ground-water flow between points on the same flowline.

Water level data from at least three piezometers and/or water table wells is necessary in establishing the maximum hydraulic gradient (i.e., the gradient in the direction of maximum slope). For a large facility or a facility with complex hydrogeology, more than three piezometers will likely be needed to establish the pattern of gradients in the area.

Porosity (total) of an earth material is its property of containing voids or interstices and may be expressed as the ratio of the volume of its interstices to its total volume (Lohman, et al, 1972). A method for determining porosity is given by Freeze and Cherry (1979, p. 237).

Effective porosity of a rock or soil refers to the amount of interconnected pore space available for fluid transmission; it is expressed as a percentage of the total volume occupied by interconnecting intersticies (Lohman, et al, 1972). When determining n for calculating the flow rate, the Agency recommends the use of effective porosity instead of total porosity, since effective porosity provides a more accurate measure of the true flow conditions. A method for determining effective porosity is described by Fetter, 1980. Effective porosity often varies with direction. Therefore, several effective porosity determinations of earth material samples in the appropriate flow zone(s) should be made so that a range of $\bar{v}$ values can be obtained.

Hydraulic conductivity of a medium is the volume of water at the existing kinematic viscosity that will move in a unit time under a unit hydraulic gradient through a unit area measured at right angles to the direction of flow (Lohman, et al; 1972). It depends primarily on the nature of the pore space (i.e., continuity of pore inter-connections), the type of liquid occupying it, and the strength of the gravitational field.

Hydraulic conductivity can be determined by laboratory and field methods. The Agency recommends that the owner or operator employ field methods whenever possible since they test the aquifer materials under in situ conditions. In general, field methods can usually provide more representative values than laboratory methods because they test a larger volume of material, thus integrating the effects of macrostructure and heterogeneities. Laboratory tests may be useful for comparison purposes with field test results. For a range of K values for different earth materials, see Freeze and Cherry (1979, p. 29).

Laboratory Methods for Determining K

Permeameters

The saturated hydraulic conductivity of an earth material sample can be measured in the laboratory using a constant-head permeameter or a falling-head permeameter. (For a more complete discussion of the apparatus and procedures, see American Society of Testing Materials; 1967 and 1978; and Freeze and Cherry, 1979). Klute (1965) believes that the constant-head system is better suited to samples with conductivities greater than 0.01 cm/min (or 1.66 x 10^{-4} cm/sec) while the falling-head system is more appropriate for samples with lower conductivity. The methods described above are applicable to common granular aquifer materials and not clayey materials. These tests provide more accurate K values when the sample is undisturbed. The heterogeneity common in earth materials will be reflected in the various K values determined for different samples. It should be recognized that permeameter tests provide K values from only sampled parts of an aquifer and may not be representative of the entire aquifer. Also, disturbance of samples during collection and handling at the laboratory can lead to inaccurate determinations.

Grain - Size Analysis

Grain-size analysis (as developed by Hazen, 1911) involves sieving of granular earth material in the fine sand to gravel range to establish the proportions of the various grain-size diameters in the sample. A representative grain-size diameter (e.g., average or median) is chosen and used in established mathematical formulae to estimate saturated hydraulic conductivity (Freeze and Cherry, 1979; pp. 350-352). Use of the median grain-size diameter for such estimates is more powerful since it considers the spread of the various grain-size diameters. In concert with mathematical calculations, curves have been developed from which K values may be read (Masch and Denny, 1966).

Grain-size analysis for estimating K is best applied to homogeneous, unconsolidated aquifers, especially when undisturbed earth material samples are obtained. Sample locations for grain-size analysis should be carefully selected since only small sample volumes are used to give an estimate of K for a larger portion of an aquifer. The greater the heterogeneity of grain-size distributions in an aquifer, the less precise is this method of determining K. This technique of estimating K is the least accurate of the techniques described in this document.

Field Methods for Determining K (For further details, see Freeze & Cherry, 1979, pp. 339-350).

Piezometer Tests

In situ K may be determined in tests using a single piezometer. These tests involve the sudden introduction or removal of a known volume of water to or from a piezometer. Observation of the recovery of the water level in the piezometer is then made. "Bail tests" involve removal of water, whereas "slug tests" involve adding of water. Interpretation of water level versus time data is dependent on the test configuration used. Methods described by Freeze and Cherry (1979), along with related mathematics, include one method for a point piezometer and another for a confined aquifer. A major limitation on slug and bail tests is their heavy dependence on a high-quality piezometer intake. Corroded or clogged well points or screens lead to highly inaccurate calculated K values. Also, development of the piezometer by surging or backwashing prior to testing may reflect the increased K values attributed to the artificially induced gravel pack around the intake.

Piezometer tests are not useful for determining K if water level recovery is too rapid to allow measurement, especially if the volume of water added or removed is small. Accurate piezometer tests provide in situ K values representative only of the small volume of porous media in the immediate vicinity of the piezometer tip. The greater the number of piezometers used, the better the characterization of the K distribution within the aquifer.

Pumping Tests

Pumping tests (also properly called aquifer tests) provide in situ measurements of aquifer coefficients (e.g., transmissivity) which can be used to calculate K over a large aquifer volume. K is computed as follows:

$$K = T/b;$$

where T is the transmissivity of the aquifer, and b is the saturated thickness of the aquifer. Pumping tests to determine K generally consist of:

- the drilling of a test well with one or more observational piezometers;
- a pumping test to determine the value of T; and
- calculation of K.

Methodology for examining pumping test data from unconfined and confined aquifers and references for pumping test configurations are discussed by Freeze and Cherry (1979, pp. 343-349). A disadvantage of pumping test data can be attributed to the nonuniqueness of its interpretation. Predicting the effects of any proposed pumping test configuration is highly dependent on a clear understanding of the geology involved. Even if pumping test data matches a theoretical curve, it does not prove that the aquifer fits the assumptions of that curve (e.g., leakage effects if present, but not accounted for, could lead to an erroneous K value for the aquifer of interest). These methods generally test larger portions of aquifers than piezometer tests. The large possibility for non-uniqueness in interpretation, problems involved in pumping contaminated fluids, and the expense of conducting such tests generally preclude their use in problems of contaminant hydrogeology.

Example of the Use of the Darcy-Based Equation

The following information was gathered for an aquifer comprised mainly of sand:

$K = 10^{-3}$ cm/s

$i = .01$

$n = .30.$

Using the equation:

$$\bar{v} = -Ki/n,$$

$\bar{v}$ is calculated to be 3.3×10^{-5} cm/s or 10.6 m/yr.

Limitations on the Use of the Darcy-Based Equation

The Darcy-based equation used in the preceding example applies to many, but not all, ground-water flow situations. For flow through granular materials there are at least two situations where valid use of this equation is in question (for more details, see Freeze and Cherry, 1979, pp. 72-75). The first deals with flow through sediments with low K values under very low gradients and the second deals with flow through sediments with very high K values. This suggests that the modified form of Darcy's equation may have both a lower and upper limit to its range of validity. Darcian-derived flow rates are rarely exceeded in nonindurated (i.e., not hardened) rocks and granular materials. However, Darcian flow rates are commonly exceeded in such important rock formations as karstic limestones and dolomites, and cavernous volcanics. Where the Darcy-based equation cannot be validly used to determine flow rate, another method (e.g., use of tracers) should be employed.

3.2.2 Use of Tracers for Determining Flow Rate

The advantage of using tracers is obvious. If the test is large enough, and for a long enough time, the actual flow path is measured rather than theoretical surrogates estimated. Generally, however, the required time will not be available.

The following discussion of tracers is based mainly on Freeze and Cherry (1979, pp. 427-430), who also provide additional references on tracers. The use of a tracer is a direct method for determining flow velocity. After introducing a tracer at one point in the flow field and observing its arrival at other points (and after making adjustments for the effect of dispersion), velocity can be computed from the travel time and distance data (i.e., $v = d/t$). Several types of nonradioactive and radioactive tracers have been used, including simple tracers such as salt ($NaCl$ or $CaCl_2$), which can be monitored by measurement of electrical conductance, to radioisotopes such as ^{3}H, ^{131}I, ^{29}Br, and ^{51}Cr-EDTA (an organic complex with ^{51}Cr), which can be monitored using radioactive detectors. Radioisotopes are subject to government licensing requirements for their use and can be hazardous when used by careless workers. Fluorescent dyes (fluoroscein and rhodamine compounds), used by many investigators, have sometimes yielded adequate results based on visual detection. When necessary, dye concentrations can also be measured quantitatively to very low concentrations. Recent work suggests that Freon (Cl_3CF) may be a very good artificial tracer, since it is nonreactive with geologic materials and can be used in extremely small concentrations that are not harmful to public waters.

Factors which should be used in selecting and using tracers include:

- ease of detection, uniqueness;
- solubility in ground water (ideally moves with water at same velocity, including direction);
- stability in ground water for desired length of time;
- type of emitted radiation, if any;
- background levels of tracer or interfering substances in ground water;
- chemical reactions among water, tracer and contaminant; and
- interactions of tracer with earth materials (e.g., filtration, adsorption).

The advantage of properly performed tracer studies is that they are indisputable. The major disadvantages of the direct tracer method include:

- because ground water moves slowly, long periods of time are normally required for tracers to move representative, meaningful distances through the flow system;
- variegated hydrogeological settings require numerous observation points (e.g., piezometers, wells, or other sampling devices) to adequately monitor the passage of the tracer through the portion of the flow field under investigation;
- if small aquifer segments are studied in order to overcome time restraints, there is less assurance that a representative sample of the flow field is tested; and

- because of the common heterogeneity of earth materials encountered, the flow field may be significantly distorted by the measuring devices.

Due to the above disadvantages, tracer experiments of this type commonly require considerable effort over extended time periods. One limited-objective technique that avoids some of these disadvantages is known as the "borehole dilution" or "point-dilution" method. This test can be performed in relatively short periods of time in a single well or piezometer and provides an estimate of the hori,atpsr slhiage flow velocity of the ground water in the formation near the well screen. In this test, a tracer is quickly introduced into a segment of a well screen isolated by packers and is then subjected to continual mixing as lateral ground-water flow gradually removes the tracer from the well bore. The combined effect of ground-water through-flow and mixing within the isolated well segment produces a dilution versus time relation from which the average horizontal velocity of ground water in the formation beyond the sand or gravel pack, but close to the well screen, is computed. This method is best suited for velocity determination in steady-state lateral flow regimes.

Borehole dilution tests can be performed at various intervals within a well screen to identify zones of highest ground-water velocity. These zones are of prime interest since contaminants can move through them at velocities much higher than in other parts of the system. Identification of such high-velocity zones, which may occur in only a thin segment of the aquifer system, will aid in the design of a more efficient monitoring network.

Most borehole dilution tests described in the literature employed radioactive tracers. However, the recent advent of commercially available electrodes for use with portable pH meters for rapid downhole measurement of Cl^- or F^- has made it feasible to conduct these tests with readily available tracers in a more convenient manner. An even simpler approach uses salt as the tracer with down-hole measurement of electrical conductance as the salt is flushed from the well screen.

3.3 Determining Extent of Contamination

This section describes methods to determine the extent of contamination. The owner or operator must determine which method(s) will be best suited to the hydrogeologic controls at his specific site.

"Extent" refers to the spatial distribution (length, width and depth) of hazardous wastes or hazardous waste constituents within the ground water environment. When a facility discharges into the subsurface, mobile constituents will migrate downward to the water table where they can migrate within the ground-water system. Contaminants in ground water often tend to travel as a "slug" or "plume", the geometry of which depends on local heterogeneities in the subsurface and contaminant properties. Ground-water contamination patterns (i.e., plume configurations) are most predictable under uniform flow conditions; however, these conditions are rarely encountered in the field. A comprehensive investigation is needed to delineate the characteristic shape or configuration of the contaminant plume(s).

Due to the variety of waste types and the complex hydrogeologic factors at many facility sites (e.g., perched water tables, local supply well pumping effects, etc.), a field investigation is the most effective method for determining the extent of contaminant migration. Several direct and indirect techniques can be utilized individually or in combination to detect and verify the configuration (i.e., extent) of a contaminant plume. Data from field investigations should be translated to site base maps and subsurface cross sections for correlation and interpretation of the results (see Section 2.2.2 for discussions of base maps and cross-sections). Information from a detailed field investigation should provide a graphic representation of the boundary or extent of the contaminated zone (e.g., by mapping isopleths of contaminant concentrations). Choice of investigative techniques should be based upon the kind and amount of waste(s) managed at the facility, the hydrogeology of the site, the size of the facility, etc. Some of the more versatile and reliable assessment techniques include:

Indirect Techniques (i.e., remote sensing)

- aerial photography;
- electromagnetic conductivity;
- electrical resistivity;
- specific conductance-temperature probe; and
- geophysical logging;

Direct Techniques include:

- boreholes with formation sampling; and
- water sampling from monitoring wells.

Not all of the above techniques need be applied to determine the extent of contaminant migration at any one site. The selection of the most effective technique(s) for a particular situation can be determined by the geologist or geotechnical engineer supervising the investigation. Although, each technique can aid in detecting contaminants in the subsurface, not every technique (especially indirect) will work satisfactorily at every site. Often, techniques work best in conjunction with one another. In some cases, it may be necessary to conduct preliminary field testing to determine the suitability of a specific technique at a given site.

Information from boreholes and monitoring wells is necessary in a ground-water quality assessment. Data obtained from other methods is often useful in supplementing the information from and determining locations of boreholes and monitoring wells. Indirect techniques can be used to reduce costs by limiting the total number of boreholes and monitoring wells necessary to define the plume.

3.3.1 Indirect Techniques

Aerial Photography

Aerial photography can serve as an initial detection mechanism to aid in determining the extent of contamination. This method provides wide surficial coverage, but is limited by the relatively poor resolution of local details. Photographic interpretation provides no subsurface data other than that which is implied, but may indicate surface responses to subsurface conditions (Benson and Glaccum, 1979). For example, vegetative stress may indicate leachate and gas migration where the water table is shallow or in discharge areas. The investigator may obtain some information on the extent of contamination by outlining the boundary of stressed vegetation. Different types of aerial photography (e.g., black and white, normal color or infrared) can detect vegetation stress which may not be evident during a field inspection. Infrared photography can be useful in determining the early effects of less advanced stresses.

Geologic features (e.g., bedrock fractures, fault zones, etc.) that affect ground-water flow patterns can be identified from aerial photos. Fractures at shallow depths in consolidated rock can serve as conduits for rapid infiltration of surface runoff. Regions where bedrock outcrops at the surface, or is overlain only by thin alluvium, are particularly susceptible to contamination. Aerial photos provide a means to detect potential avenues of contamination in areas characterized by outcropping fractured bedrock.

Contamination of surface water bodies may be detected by discoloration or shading in aerial photography. This information may enable the investigator to make a quick, rough assessment of the extent of potential contamination of such surface water.

Land surface elevation determinations and contour maps (photogrammetry) can be compiled from information in aerial photographs and ground-water flow direction in shallow systems can be estimated using this information.

Federal and other offices serve as repositories of aerial photographs especially for historical or pre-discharge imagery. Photos may be purchased or information on photos obtained from the sources identified in Section 2.2.2.

It may be necessary to retain a contractor to fly aerial surveys of a particular area to achieve the timeliness and level of detail desired in the area to be assessed. Enlargements of photos can be made, but at a loss of resolution.

Conclusions drawn from the interpretation of aerial photographs should be substantiated by surface inspection. Aerial photography serves primarily as an aid for designing a more detailed assessment strategy that should include other field methods.

Advantages and Limitations of Aerial Photography

Advantages include:

- it is relatively inexpensive;
- it is an easily accessible technique which provides information on a large area;
- it may indicate the effects of the contamination as well; and
- it serves as a good preliminary step in evaluating an affected area.

Limitations include:

- it provides relatively poor resolution of local details; and
- it offers no direct information on subsurface characteristics.

Example of the Use of Aerial Photography

Low levels of some organic chemicals (trichloroethylene, toluene and benezene) were detected in several farmers wells in a sparsely developed, limestone valley. The suspected source of the contaminants was a waste impoundment which was located approximately 1/4 mile away. There were no detailed maps of the area; however, aerial photos taken by the U.S. Soil Conservation Service in the winter of 1957 were available in stereo pairs. It was apparent from the photos that the shallow limestone bedrock had a very definite control on the topography and other surface features. There were numerous springs, sink holes and streams in the area that seemed to be aligned in a general rectangular pattern.

Aerial photography was used to obtain more recent color photos on a larger scale plus false color infra red (IR). The IR photos were helpful in identifying springs and other points of ground-water discharges. Areas of stressed vegetation were identified. Two ponds and a drainage ditch in the area also appeared to be a darker tone of color than other ponds in the vicinity, indicating possible contaminant migration.

From the larger scale aerial photos, pertinent information was added to a base map. The impoundment, contaminated wells and wells yet to be sampled were located on the map. Also included were springs, ponds, sink holes, streams, stressed vegetation areas, stained drainage ditches and other areas of suspected contamination. The above observations required verification by field inspection, including groundwater sampling and analysis. After employing these techniques, the confirmed contaminated areas were plotted on the base map. The map indicated that the extent of the contaminated zone reflected the same general rectangular pattern described in the aerial photos. The contaminants were most likely migrating through solution cavities that were developed along joints in the limestone bedrock.

Electromagnetic Conductivity

Electromagnetic conductivity (EM) is a geophysical technique capable of obtaining data on subsurface conditions. EM can detect subsurface features capable of conducting an electric current and is especially useful in defining shallow ground-water zones characterized by high dissolved solids (e.g.contamination plumes).

EM operates in the following manner: The transmitting coil generates alternating magnetic fields which result in the flow of alternating currents that are detected by the receiving coil. The intensity of alternating currents is greater in areas of high conductivity and, conversely, lower in areas of low conductivity (Griffiths and King, 1966). Electromagnetic conductive properties are a function of the basic soil/rock matrix (e.g., grain size, porosity, and permeability) and also of the fluids which permeate the matrix. Contamination often increases the free ionic content of the ground water, hence increasing its conductivity. EM techniques comprise a composite measure of these properties which, like aerial photography, supplement other data in a contamination assessment (Benson and Glaccum, 1979, 1980).

EM equipment does not require ground connections, is very mobile and can be operated over a variety of terrains. The data is recorded in a series of profiles, which indicate shape and trends of anomalous subsurface conditions.

Advantages and Limitations of EM

Advantages include:

- instrumentation is fairly easy to operate;
- surveys can be completed in a relatively short period of time since ground connections are not necessary;
- it can provide a quick preliminary assessment of shallow contamination; and
- it is relatively inexpensive.

Limitations include:

- data is limited to shallow depths;
- instrumentation is sensitive to interference from conducting bodies at or above the surface (e.g., transmission wires);
- it provides qualitative information which requires substantiation by direct techniques; and
- results must be compared to background information, including local geology and ambient ground-water chemistry.

Example of the Use of EM

Monitoring wells detected a discharge from an impoundment containing pickeling liquors in a valley comprised of alluvial deposits. Because a municipal well field was nearby, the ground-water around the impoundment was carefully monitored. Due to the presence of highly permeable, shallow, but discontinuous channel deposits, there was concern that the contaminants would be difficult to trace along an irregular ground-water flow pathway.

EM was selected as an assessment method because the contaminant was highly conductive within the shallow channel sand deposits. Numerous traverses of the area downgradient from the impoundment were made in order to account for the variability of the subsurface deposits. The responses of the equipment were continually recorded on a portable strip chart recorder as shown on Figure 3-1. Station points (i.e., flagged stakes) surveyed in for field control provided quick references for locations, and facilitated the transfer of data to a base map of the area. Interpretation of the results involved primarily the recognition of significant anomalies, the outline of which indicated the extent of the contaminated zone. The extent of migration was verified by drilling additional boreholes with monitoring well sampling and analysis.

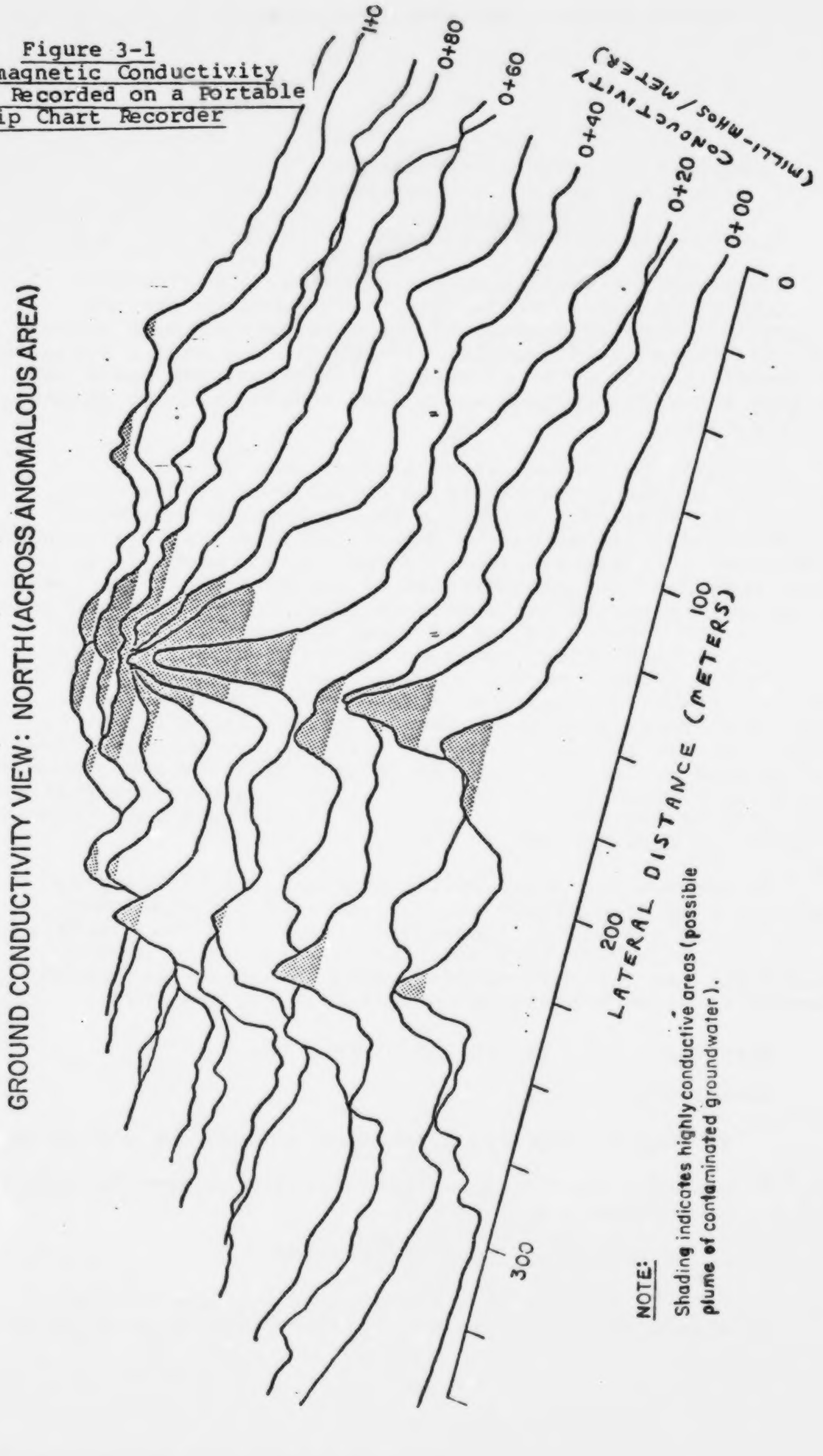
Electrical Resistivity

Owners and operators are encouraged to explore the utility of electrical resistivity (ER) in defining the plume of contamination. The procedure is based on transmission of an electric current into the subsurface materials and measurement of the materials' resistance to the flow of that current. Low resistivity values can indicate a concentration of free or mobile ions, such as are often found in contaminated ground water. ER is particularly useful for facilities receiving inorganic wastes at sites characterized by homogeneous geological conditions.

Resistivity surveys at established plumes are in general the cheapest and most reliable technique for defining the edge of the plume and the rate of migration. Established grids re-surveyed quarterly with knowledge of water table fluctuations can provide a convincing demonstration of these two factors.

The most commonly used approach in conducting an ER survey utilizes the Wenner electrode configuration in which four electrodes (copper coated steel rods) are pushed or hammered several inches into the ground along a straight line. The electrodes are spaced at equal intervals ("A-spacings") determined by the depth of interest. Under uniform conditions, the A-spacing is roughly equivalent to the depth of interest. An electric current (I) from a battery is applied by conduction into the ground through the outer two electrodes. The current distributes itself throughout the volume of earth materials in between. The resulting voltage drop (V) is measured across the inner two electrodes. The "apparent resistivity", R_a, is then determined for graphing purposes. Some ER instruments can automatically compute the apparent resistivity; otherwise it can be computed as follows:

Figure 3-1
Electromagnetic Conductivity Responses Recorded on a Portable Strip Chart Recorder



NOTE:
Shading indicates highly conductive areas (possible plume of contaminated groundwater).

$R_a = 2 \quad A \quad V/I$;

where R_a = apparent resistivity;
A = spacing between electrodes;
V = voltage; and
I = electric current.

Apparent resistivity values of subsurface materials obtained by ER measurements made at the surface are the composite or average values of the materials through which the electric current travels. Irregularities (e.g., variations in composition of earth materials) in resistivity below the surface alter the pattern of current distribution of potential differences.

In order to conduct an ER survey, control points, baselines and/or grids should be established by measuring, staking and flagging benchmarks at appropriate intervals. The depth of interest can be determined from vertical soundings, from which the lateral extent of the contaminated ground-water body can then be estimated by constant-depth surveying. ER values are plotted on a grid or base map and then contours can be drawn between points of equal apparent resistivity. There is no theoretical limit to the depth of an electrical resistivity investigation. However, at depths exceeding 100-200 feet results become more difficult to interpret (e.g., small anomalies are masked) because of the large volume of earth material through which the electric current must flow. The success of ER in contamination assessment is also dependent on the particular contaminant's ability to affect detectable decreases in resistivity (i.e., not all contaminants cause a decrease in resistivity).

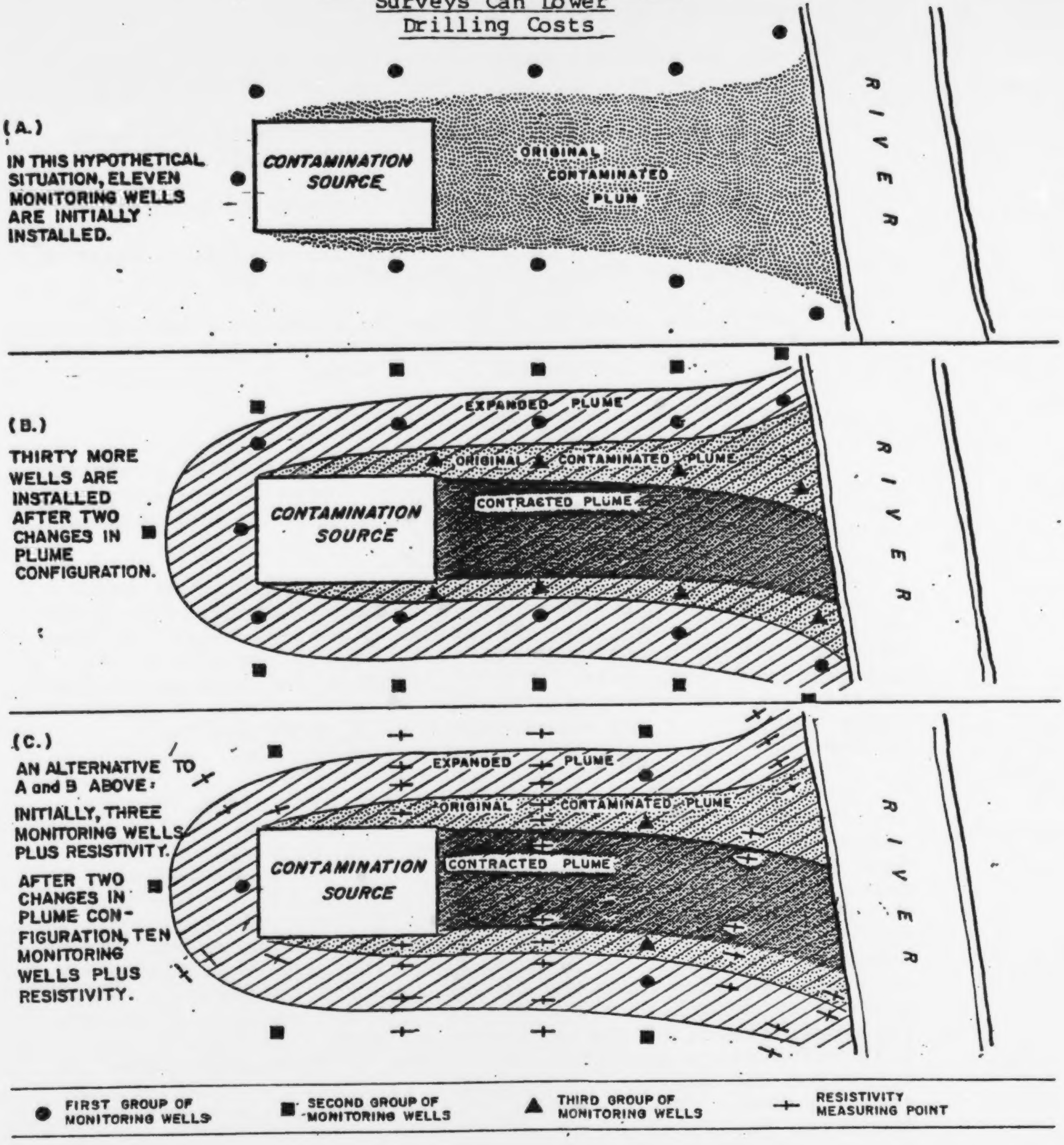
ER surveys can lower drilling costs (see Figure 3-2). Wells drilled only around the perimeter of a contaminant plume are by themselves inadequate in defining the extent of the plume as it contracts and expands. ER can be used to supplement the information from wells to aid in monitoring changes in plume configuration at relatively low cost.

Advantages and Limitations of ER

Advantages include:

- it aids in defining subsurface geology and contamination;
- a survey can be re-run periodically to provide updated monitoring data;
- it is relatively inexpensive; and
- it aids considerably in defining the application of direct techniques (e.g., boreholes and monitoring wells).

Figure 3-2
How Electrical Resistivity
Surveys Can Lower
Drilling Costs


(A.)
IN THIS HYPOTHETICAL SITUATION, ELEVEN MONITORING WELLS ARE INITIALLY INSTALLED.
CONTAMINATION SOURCE
ORIGINAL CONTAMINATED PLUME
RIVER
(B.)
THIRTY MORE WELLS ARE INSTALLED AFTER TWO CHANGES IN PLUME CONFIGURATION.
EXPANDED PLUME
ORIGINAL CONTAMINATED PLUME
CONTRACTED PLUME
CONTAMINATION SOURCE
RIVER
(C.)
AN ALTERNATIVE TO A and B ABOVE:
INITIALLY, THREE MONITORING WELLS PLUS RESISTIVITY.
AFTER TWO CHANGES IN PLUME CONFIGURATION, TEN MONITORING WELLS PLUS RESISTIVITY.
EXPANDED PLUME
ORIGINAL CONTAMINATED PLUME
CONTRACTED PLUME
CONTAMINATION SOURCE
RIVER
● FIRST GROUP OF MONITORING WELLS
■ SECOND GROUP OF MONITORING WELLS
▲ THIRD GROUP OF MONITORING WELLS
+ RESISTIVITY MEASURING POINT

Limitations include:

- the greater the depth of interest, the less accurate are interpretations concerning contaminant migration;
- variations in geology (e.g., clay lenses) can mask the effects attributable to contamination;
- not all contaminants result in lower ER values;
- background data on natural quality of ground water and geology is a necessary prerequisite; and
- potential interferences due to conducting bodies (e.g., metal pipes and fences) at or below the land surface can hinder interpretation of data.

Example of the Use of ER

Leachate from a landfill situated in a coastal plain was determined to be contaminating several wells in the vicinity. The contaminants consisted primarily of arsenic and various heavy metals.

The detection of leachate by ER is a function of the leachate's electrolytic properties. Many leachates are high in dissolved ions and are considered good conductors (or have low resistivity) when compared to background levels of the natural earth materials. For this reason and because of the relatively shallow depth of interest (i.e., depth to water table < 100 feet), ER was selected as a technique for determining the extent of contaminant migration.

In order to estimate the depths of investigation and thus the electrode A-spacing, ER soundings (i.e., multi-depth readings) were conducted at various locations downgradient from the landfill. Once the most effective A-spacing was determined, baselines were established and the entire area was profiled (i.e., constant A-spacing was used) with approximately 200 electrical resistivity measurements. The apparent resistivity values obtained from these measurements were plotted on a base map of the area and compared to other sources of information. Contours of these values indicated the areal extent of the contaminated zone (see Figure 3-3). This information provided a basis for locating sites for boreholes and monitoring wells for verifying the results of the ER survey. The boreholes and wells were also needed to determine the depth component of extent, which could not be determined adequately by indirect techniques.

For further information on ER concerning equipment, procedures,data interpretation and case studies; see Roux (1978).

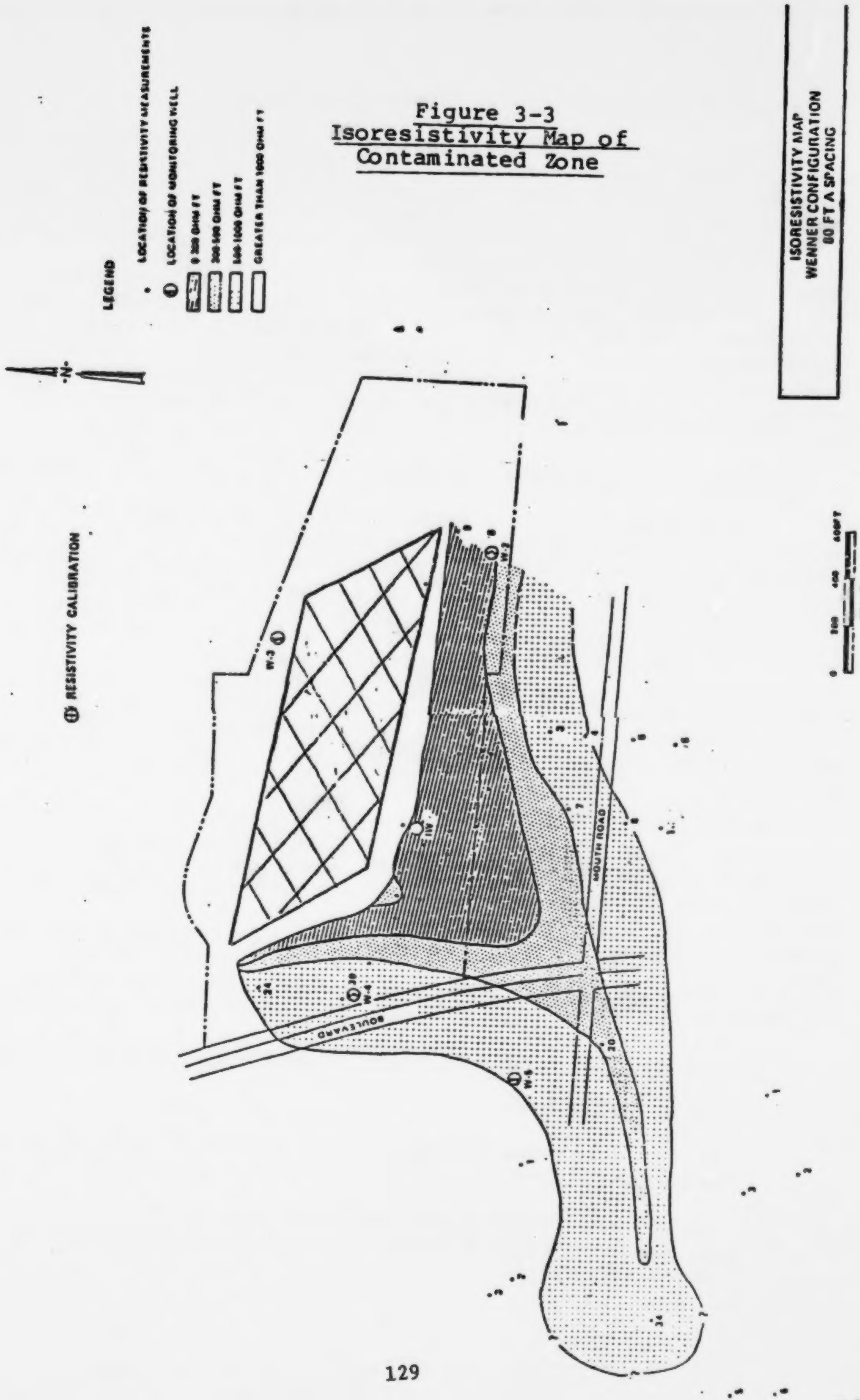

LEGEND
● LOCATION OF RESISTIVITY MEASUREMENTS
⦶ LOCATION OF MONITORING WELL
0-200 OHM FT
200-500 OHM FT
500-1000 OHM FT
GREATER THAN 1000 OHM FT
⦶ RESISTIVITY CALIBRATION
N
W-3
W-2
W-1
W-4
W-5
W-6
BOULEVARD
MOUTH ROAD
ISORESISTIVITY MAP
WENNER CONFIGURATION
80 FT A SPACING
0 200 400 600FT
SCALE

Figure 3-3
Isoresistivity Map of
Contaminated Zone

Specific Conductance and Temperature Probes

Since a facility discharge (i.e., leachate) may have substantially higher temperature and specific conductance than natural ground water, the presence of such leachate can be detected by these two characteristics. Measurements of these characteristics can be made by lowering a remote sensing device into a well and recording results from surface instrumentation. In areas with a high water table, however, the measurements can be made without installing a well. The method involves the use of a self-contained conductance-temperature probe which can be pushed into soft ground or inserted into a hand-augered hole to reach the saturated zone. (For further information on this method see Fenn, et al, 1977, pp 119-121.)

Geophysical Borehole Logging

Geophysical logging methods can greatly enhance the amount of information gained from a borehole. Each method is designed to operate in specific borehole conditions, involves lowering a sensing device into the borehole and can be interpreted to determine lithology, geometry, resistivity, bulk density, porosity, permeability, moisture content and to define the source, movement, chemical and physical characteristics of ground water. Logs produced by geophysical methods include: spontaneous potential, normal resistivity, natural gamma, gamma-gamma, caliper, temperature and fluid conductivity. Specific functions of these logs are discussed by Scalf et al.(1981; pp. 34-36) and Keys and MacCary (1971).

Geophysical well logging is applicable only to those subsurface investigations which include test drilling and is therefore not an independent tool. Interpretation of well logs is most reliable when several techniques are used and the resulting logs are placed side by side to allow crosschecking. Such cross-checking with the driller's/geologist's log is also recommended. Detailed interpretation of well logs can be used to evaluate ground-water characteristics. Correlation is often difficult and should be done by a specialist.

Advantages and Limitations of Geophysical Borehole Logging

Advantages include:

- it can determine formation changes which aid in determining contamination pathways; and
- it can aid in locating the vertical limits of a plume of contamination through definition of ground-water characteristics.

Limitations include:

- it necessitates the use of special, relatively expensive equipment and trained operators;
- its requires drilling of boreholes; and
- results are qualitative (i.e., concentrations of specific contaminants are not determined).

3.3.2 Direct Techniques

Direct assessment techniques involve collection, observation and analysis of earth materials, including water samples.

Direct methods (e.g., boreholes and monitoring wells) which entail excavation or drilling necessitate careful and prompt recording of all data, such as:

- location of the borehole on a base map;
- assignment of an identification number;
- elevation of the ground surface (accurately determined
- elevation of the top of casing of the well; - drilling method;
- hole diameter;
- depth of samples;
- method of subsurface sample collection;
- description of field materials; - if borehole is completed as a well -- length, diameter and type of casing;
- length, diameter, type and setting of screen, if used;
- gravel pack (size), backfill and grouting materials and related depths;
- date, time, weather conditions; and
- name of supervising geologist.

Boreholes and Monitoring Wells

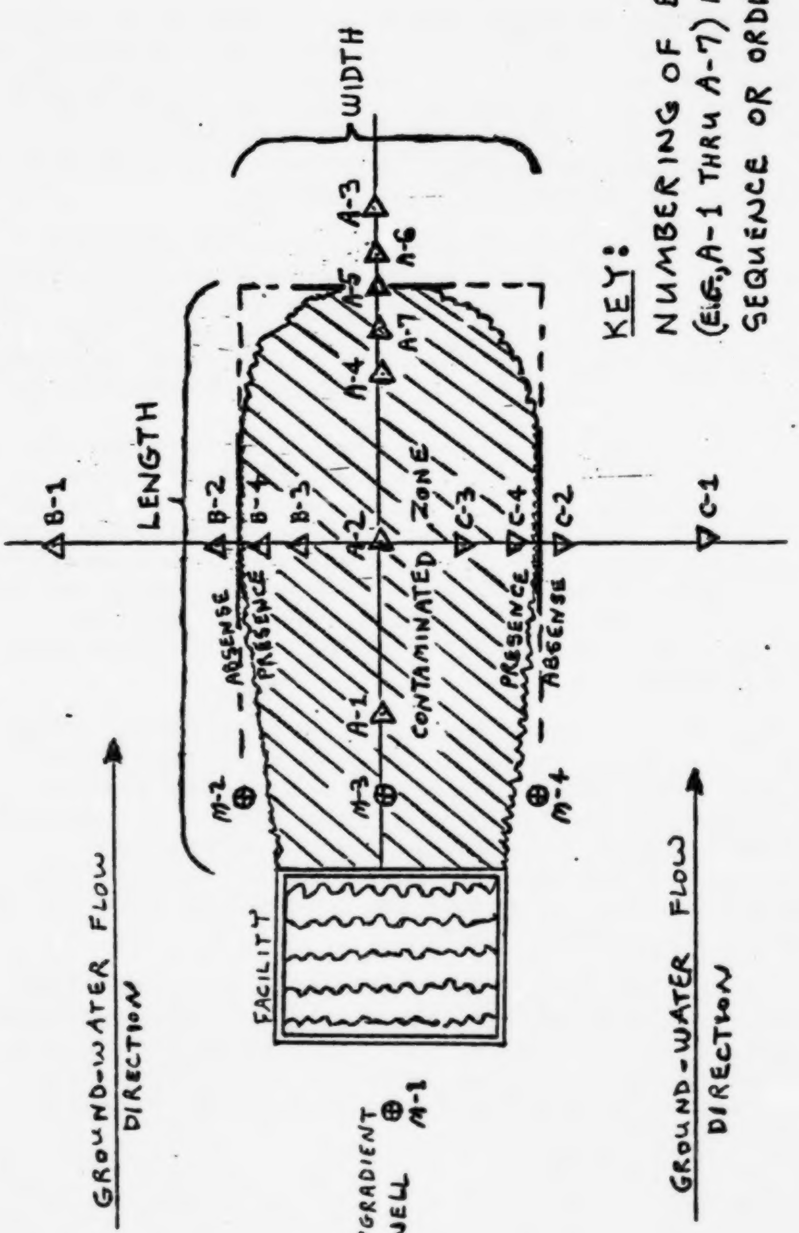
Purposes for drilling boreholes are discussed in Section 2.2.1. Locations and depths of boreholes and monitoring wells may be based, in part, on the findings of indirect methods (e.g., ER and EM) and spaced so as to provide sufficient coverage of the areas most likely to be affected by contaminants. Since results of indirect methods are not conclusive, the initial boreholes should be drilled close to the probable source of contamination. Subsequent boreholes should be located radially outward increasing with distance until the contaminant front is delineated.

Figure 3-4 illustrates an example of a systematic approach for spacing which may be used in determining locations for boreholes and monitoring wells when information on the distribution of contaminants at a given site is limited. (For further information on well location, number, design and installation, see Sections 2.2 and 2.3). If well M-3 is found to be contaminated, it may be appropriate to drill a series of wells downgradient of the facility along a line parallel to the direction of ground-water flow. For example, well A-1 is drilled at a location twice the distance between M-3 and the facility. If this well is found to be contaminated, a second well (A-2) is drilled along the same axis twice the distance between A-1 and the facility, and so on, always doubling the spacing between wells until contaminants are not detected in the most distant well. A-4 is then drilled halfway between A-3 (clean) and A-2 (contaminated), A-5 between A-3 (clean) and A-4 (contaminated), etc., until the distance the plume has traveled has been located with reasonable accuracy.

Likewise, in delineating the width of a plume, on a line perpendicular to the direction of ground-water flow, through well A-2 (thought to be near the center of the plume), well B-1 is drilled at a distance from A-2 equal to that between A-2 and the facility. If this well is free of contaminants, well B-2 is drilled halfway between B-1 and A-2, B-3 between A-2 and B-2 and so on. The same procedure is used in locating wells between A-2 and C-1. This example approach defines the extent of the plume with a minimum of drilling effort and expense, since wells are clustered close to the boundaries of the contaminated area. These wells can be used to detect any further expansion or contraction of the plume. Plume thickness should also be determined by using methods such as well clustering or employing wells which enable discreet, multiple depth sampling within a single borehole.

Boreholes and monitoring wells can be installed by a variety of drilling techniques (see Section 2.3.2). Regardless of the type of drilling method selected, extreme care must be taken to insure against creating a conduit for contaminants to flow from contaminated to uncontaminated aquifers or aquifer zones. The geologist or geotechnical engineer directing the assessment should work with the driller to prevent this from occurring.

Figure 3-4
Borehole/Monitoring Well
Plan for Determining Extent
of Contamination


GROUND-WATER FLOW DIRECTION
GROUND-WATER FLOW DIRECTION
UPGRADIENT WELL
M-1
FACILITY
M-2
M-3
M-4
A-1
A-2
A-3
A-4
A-5
A-6
A-7
B-1
B-2
B-3
B-4
C-1
C-2
C-3
C-4
LENGTH
WIDTH
CONTAMINATED ZONE
ABSENSE
PRESENCE
PRESENCE
ABSENSE

KEY:
NUMBERING OF BOREHOLES
(E.G., A-1 THRU A-7) INDICATES THE
SEQUENCE OR ORDER FOR DRILLING

Boreholes, completed as piezometers and/or monitoring wells, can provide information on composition of earth material formations, contaminant concentrations, water elevations, flow directions, etc. (see Sections 2.2 and 2.3). Drilling data should be recorded in a format which allows comparison with published geological maps and available well-log records.

Example of the Use of Boreholes and Monitoring Wells

Contaminants from an impoundment are known to be migrating toward a municipal well field in which wells are screened at various depths (100 ft. to 500 ft.) within an alluvial fan deposit. Trace levels of contaminants have been detected in a few scattered monitoring wells, but the distribution of contaminants within the multi-level aquifer is unknown due to the complexity of the subsurface flow system.

To determine the extent of contamination at various depths within this multi-level aquifer, boreholes were drilled to obtain formation samples and to perform geophysical logging. Monitoring wells were installed in some of the boreholes and sampled for the indicator parameters, described in Section 2.4.5, to screen for more specific contaminants.

Detecting low levels of contaminants requires special care in drilling and obtaining representative solid and water samples. The boreholes were fully cased so as to reduce caving and contamination of samples by near-surface materials. The drilling fluid consisted only of pure bentonite (no additives) and clean tap water. A non-reactive tracer was added so that the presence of drilling fluid within a sample could be detected readily. Also the drilling fluid was periodically tested for contamination.

Split spoon samples were obtained at least every five feet. Geophysical logging aided in determining the depths of the contaminated zones and for correlating strata between boreholes.In selecting the optimum intake location, consideration was given to the spatial distibution of the suspected contaminant zones and the intake locations in surrounding wells. The objective was to assure as complete a coverage as possible of the contaminant front.

Monitoring for the indicator parameters also provided valuable information concerning the extent of contamination within this ground-water system. Specific conductance and pH were measured in the field by lowering sensing devices down wells or immersing these devices in samples of water obtained at the site.

Safety

Safety is an important consideration when using field methods to define contamination. Appropriate protective clothing, such as gloves and boots, should be worn. If the contaminants are suspected of causing respiratory damage, special breathing apparatus (e.g., ultra-twin respirators or self contained breathing apparatus) will be needed. When toxic contaminants are suspected, field testing should be performed only by personnel trained to work with hazardous waste and samples should be analyzed by a qualified laboratory.

3.4 Determining Concentrations of Contaminants

The term "concentration" in this discussion refers to the mass of solute (i.e., hazardous waste or hazardous waste constituent) present in a known volume of ground water. Concentration is commonly expressed in milligrams per liter (mg/l) or micrograms per liter (g/l). Accurate determination of the concentration of hazardous waste or hazardous waste constituents present at each sampling location provides the owner or operator and the Regional Administrator with information necessary to evaluate the severity of contamination in the ground water.

Sampling points (e.g., monitoring wells) should be located in relation to defining the contaminant plume(s). Information on "uncontaminated" ground-water quality upgradient of the facility is useful in determining the severity of any downgradient contamination and can also help to account for any upgradient contamination sources. Contaminant concentrations within the plume will vary (e.g., due to dilution and attenuation effects, there may be gradation in contaminant concentrations from high levels nearest the facility through the middle of the plume, to lower levels near the outer limits of the plume). Therefore, the owner or operator should obtain ground-water samples which will reveal a range of concentrations that exist within the plume. The concentration values obtained from these samples should be evaluated in the context of their location within the plume and their relationship to any background and other sample values obtained. Concentration isopleth maps should be prepared for parameters of concern. Such maps should depict the lateral and vertical extent of plume migration.

The following discussions present general procedures and methods for obtaining accurate concentration values for hazardous waste or hazardous waste constituents in ground water underlying a facility. Scenarios for "simple cases" and "complex cases" are presented.

3.4.1 Simple Case Determinations

In a simple case, accurate information on the identity, composition, and location of past and present wastes at the facility is readily available through existing records. This information is necessary for determining concentrations since knowledge of the types of waste will aid in selecting specific compounds and elements to be analyzed for in groundwater samples.

Compile a List of Potential Contaminants

The first step in determining concentrations is to compile a list of those hazardous wastes or hazardous waste constituents to be analyzed in ground-water samples. "Hazardous waste constituent", as defined in 40 CFR §260.10(a)(8) means a constituent which caused the Administrator to list the hazardous waste in 40 CFR Part 261, Subpart D, or a constituent listed in Table 1 of 40 CFR §261.24. In addition to wastes managed in current operations, wastes handled in the past should be included in the sampling and analysis scheme because of the potential persistence of ground-water contamination over long time periods. Older wastes may have migrated through past or recent facility discharges.

The types of information which should be used in compiling the list of hazardous wastes and hazardous waste constituents include:

- General Waste Analysis -- The facility owner or operator is required by 40 CFR 265.13 to obtain a detailed chemical and physical analysis of a representative sample of the waste. This analysis must contain all the information which must be known to treat, store or dispose of the waste. The analysis may include data developed under 40 CFR Part 261 of the RCRA regulations for identifying hazardous wastes, and existing published or documented data on the hazardous waste or on waste generated from similar processes. Applicable wastes include those identified according to characteristics in 40 CFR Part 261, Subpart C and those listed in 40 CFR Part 261, Subpart D. A detailed analysis will identify many different waste properties (e.g., pH, density and viscosity), including the composition of the waste and relative quantity of each component. The extent to which the waste composition will be described depends upon the complexity of the waste and the information needed for proper waste management.

- Generator Manifests -- The manifest required under 40 CFR Part 262 to accompany the shipment of hazardous waste contains information from the waste generator describing the wastes and the quantities of each waste by weight or volume. The facility owner or operator should have obtained this manifest information from the waste transporter upon acceptance of the waste at his facility.

- Facility Operating Records -- Operating records maintained at the facility may provide additional information on waste composition and the identity of hazardous substances that should be analyzed for, especially for wastes handled in the past. When reviewing these records, the owner or operator should pay particular attention to data on the identity of the waste, the management processes used, the identity of material recycled or recovered, and the identity of generators from which waste was accepted. These types of information will aid the owner or operator in determining what hazardous wastes have been or are being managed at the facility.

- Additional information sources -- For those periods in which facility operating or other records are incomplete, "historical records" may provide supplemental information. Records such as old aerial photographs and records of previous ownership of the facility may be used to deduce generally what types of wastes have been managed in the past and where they were treated, stored and/or disposed of. In some cases, interviews with former employees may be helpful.

Sampling Procedures

The next step in determining concentrations is to select and implement sampling procedures appropriate for the substances on the compiled list. In general, the sampling procedures and methods described for the detection program in Section 2.4 should be employed. The assessment may involve specific analyses of a variety of complex substances and mixtures in ground water. Sampling procedures, as in detection program monitoring, should be selected so as to have the least effect on the quality of the monitored parameters (see Scalf, et al; 1981; pp. 43-71, 87-93).

It is strongly recommended that the owner or operator consult with the laboratory personnel to whom he will be submitting samples on the hazardous parameters for analysis (refer to comprehensive list) and receive recommendations for any specialized sample collection and/or handling procedures necessary.

Analytical Procedures

After determining the appropriate sampling procedures, the owner or operator must determine appropriate analytical procedures (see Section 2.4). Acceptable procedures can be found in the references in Table 2-3 or from comparable analytical references. The owner or operator should select appropriate analytical methods in consultation with the laboratory, taking into account the parameters to be analyzed, appropriate (i.e., state of the art) concentration detection limits and instrumentation required.

After analysis, the owner or operator should receive from the laboratory a report documenting the analyzed substances and their respective concentrations or values found in each sample. The owner or operator should examine the report to ensure that all samples sent to the laboratory were analyzed and that all requested concentration determinations have been made. In addition, the owner or operator should note any high or low concentration values for a particular parameter, relative to determinations for all other samples. Anomalous concentration values may indicate possible human error or unusual site conditions that warrant closer scrutiny during future assessments.

3.4.2 Complex Case Determinations

In a complex case, it is assumed that existing facility records do not provide sufficient information for completing a list of all hazardous wastes managed by the facility. Other methods for identifying these substances must be employed in order to compile a list.

Compiling a list

All records that do exist for waste handled during past and present facility operations should be utilized to compile a preliminary list of hazardous wastes. The sources described in the preceding simple case discussion should provide any available records on waste composition. The owner or operator should also review the indicator parameter data for the affected downgradient well(s) generated during the detection program (if implemented). The data for pH, specific conductance, total organic carbon (TOC), and total organic halogen (TOX), can provide a general qualitative assessment of the ground water, indicating the types of substances present. An increase in specific conductance or a change in pH value would indicate the presence of inorganic compounds. An increase in TOC and TOX would indicate that organic substances had entered the ground water.

Another step in identifying components of the waste is to screen the potential contaminants in the waste management area by collecting representative samples of the waste if this can be done safely (e.g., at various levels of a surface impoundment, or at different locations at a landfill). These samples should then be analyzed by a laboratory using procedures similar to those for a general waste analysis (see simple case discussion). Procedures for sample collection and analysis may be those specified by the facility's written waste analysis plan required by 40 CFR Part 265.13(b). This screening method will provide information concerning waste composition (e.g., chemical classes and individual compounds). Any waste components identified by screening of the waste management area should be added to the list for analysis of ground-water samples.

Data collected from on-site investigations should be compared against the list of substances compiled from existing records to determine if the results verify the existing list and/or identify additional hazardous parameters that should be analyzed. The use of both existing records and field screening techniques aid in compiling a more comprehensive list of contaminants. If the owner or operator does not view the "final" list of hazardous wastes as sufficient, despite the on-site surveys, he should request that the laboratory scan the samples (e.g., using gas chromatography/ mass spectrometry) to determine other specific parameters.

Sampling and Analysis Procedures

The general procedures for sampling and analysis remain the same as for simple case determinations described earlier.

3.5 Case Studies

Two simplified case studies are presented below to illustrate methods for conducting a ground-water quality assessment.

Glacial Aquifer

Introduction

Wastes containing chromium have been disposed in a surface impoundment located in a formation composed of glacial outwash sediments. The disposal site is bounded to the south by a small creek that may serve as a discharge area. Data from water quality analyses (downgradient private supply wells) indicate that chromium-containing leachate has percolated down through the unsaturated zone, contaminating the ground-water supply. Ground-water quality assessment efforts include tracking the extent of the leachate plume, determining the rate of plume migration and determining concentrations of the parameters of interest.

Hydrogeologic Framework

Information from available literature indicates that the impoundment is located in an aquifer composed of glacial outwash material with a saturated thickness of 25-43 meters. The aquifer consists of beds and lenses of fine to coarse sand and gravel, with thin lenses and beds of fine to medium sand and silt interbedded with the coarser material.

Assessment Methodology

In the assessment strategy, surface geophysical techniques can be utilized to aid in determining the extent of contamination. Information to aid in determining the lateral and vertical extent of the plume can be acquired by conducting an electrical resistivity survey. Assuming there is no interference from transmission lines or underground pipes, etc., an unconsolidated aquifer (e.g. glacial) with a relatively shallow water table may provide a satisfactory setting for conducting such a survey.

The nature of the contamination indicates an apparent resistivity 5 to 10 times lower than that of the regional ground water. Since contaminated ground water in this particular discharge had a high free ion content, the resistivity values obtained were well-defined on a resistivity contour map. Significant changes in the contours may aid in identifying the extent of the plume. In addition, an electromagnetic conductivity survey can corroborate the resistivity findings and assist in planning borehole/monitoring well locations.

On the basis of results obtained from the above surveys, boreholes and monitoring wells were installed. The location of boreholes/wells should provide data on background water quality and the rate and extent of ground-water contamination. Formation samples should be obtained at appropriate intervals during the drilling of boreholes. The installation of boreholes/wells should continue until the limits of contamination can be ascertained.

Determination of hydraulic conductivity should be made by field methods. In addition, water level elevations obtained from the monitoring wells can be used to construct a flow net to indicate the hydraulic gradient(s). Then, the Darcy-based equation ($\bar{V} = Ki/n$) can be applied to determine the average velocity ($\bar{V}$) of movement.

Concentrations of the parameters of interest should be determined for each sampling point. Contaminant concentration isopleth maps should be drawn for parameters of interest to depict lateral and vertical spread.

Limestone Aquifer Introduction

Significant ground-water contamination was suspected in the vicinity of a plant site consisting of a number of surface impoundments which are used to settle effluent from the industry's waste-water treatment facility. Organic solvents (including benzene) are known to be components of the plant waste stream.

Hydrogeologic Framework

Available historical data and field observations indicate that the area is underlain by approximately 6 to 12 m of clay over fractured limestone bedrock. This clay has a very low hydraulic conductivity and may act as a confining layer for the underlying limestone aquifer. Faults in the limestone act as ground-water conduits, with broken and brecciated material having a high porosity and high hydraulic conductivity.

Assessment Methodology

The water level in this area is at the limestone and clay interface. Production wells in this area are cased in the limestone aquifer. One downgradient production well in the area exhibited high concentrations of benzene and other organic solvents.

The techniques of electrical resistivity and electomagnetic conductivity would likely be inappropriate in this setting as the clay content of the overburden material would mask low resistive or high conductive values commonly found in contaminated ground water. Also, these methods would not be appropriate to detect these contaminants. However, aerial photography is a useful technique in this geologic setting. The photographs may indicate surface manifestations of fractures in the limestone formation which will be of value in discerning the ground-water flow within the aquifer. These fracture traces can also delineate areas where high concentrations of contaminants are suspected. The production well exhibiting high concentrations of benzene and other organic solvents is 200 feet downgradient from an impoundment excavated down to the limestone interface. Migration of contaminants occurs along the top of the limestone formation and through solution joints.

Considerations for determining the location of monitoring wells should include the concentration of benzene and other organic solvents in the production well (200 feet downgradient from the source) and the location of fracture traces in the limestone formation. Particular attention should be payed to intersections of these fractures. Such monitoring wells, cased at different intervals within the limestone formation, can provide data concerning the movement of contaminants through solution joints.

Once the length, breadth and depth of the plume of contamination have been identified, it is essential to determine the rate of movement. This will enable rough predictions to be made of when contaminants will reach downgradient water supplies. The Darcy-based equation may be applied to determine the flow rate if the suspected rate falls within the equation's useful limits (see Freeze and Cherry, 1979, pp. 72-73). If not within these limits, other rate-determining methods (e.g., use of tracers) should be used.

3.6 Recordkeeping and Reporting

Recordkeeping

The owner or operator is required by §265.94(b)(1) to keep records of all analyses and evaluations specified in his ground-water quality assessment plan. In this way, the most current information on the rate and extent of contaminant migration and the concentration of contaminants in the ground water is readily available. These records must satisfy the requirements of §265.93(d)(3) and must be kept until final closure of the facility; and, for disposal facilities, throughout the post-closure care period as well. The recorded information must include:

- the number, location, and depth of wells; the number and location of any other sampling locations;
- sampling and analytical methods (e.g., field screening techniques) for those hazardous wastes or hazardous waste constituents in the facility;
- evaluation procedures, including any use of previouslygathered ground-water quality information; and
- the schedule (i.e., chronology) of implementation.

The content and organization of these records must clearly reflect the results of the ground-water quality assessment program according to the objectives of defining the rate and extent of contaminant migration and the concentration of contaminants in the ground water. Relevant site-specific conditions should be highlighted. Records should be readily accessible to both the owner or operator and the Regional Administrator at all times. Data should be maintained in an organized manner and be reproducible.

Reporting

Section 265.93(d)(5) requires reporting assessment results to the Regional Administrator within fifteen days of the first determination. Subsequent assessment reports must be submitted annually. See the "Note" in Section 2.5.3 concerning annual reports under §265.75. Assessment reports should include:

- the calculated (or measured) rate of migration of contaminants;
- the extent of migration of contaminants (i.e., distance traveled from source and approximate spatial configuration of ground water affected); and
- the concentration of hazardous waste or hazardous waste constituents in the ground water.

The first assessment report will give the Agency information about the nature of the contamination (if it has been determined that a facility discharge entered the ground water). This report will supplement the written notice from the detection program (if it was implemented) that the facility may be affecting ground-water quality. Thus, the Agency is informed as soon as possible of the status of contaminated aquifers.

Subsequent assessment reporting assures that the Agency has updated information on the ground-water contamination problem. Knowing the concentration, migration rate and extent of hazardous waste or hazardous waste constituents in ground water will aid the Agency in determining any potential threat which may be posed to human health or the environment in the vicinity of the facility and in determining any appropriate action needed. The format of these reports should provide a clear identification of the information given and employ a logical order of discussion.

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Appendix A - Interim Status Ground-Water Monitoring Regulations

Subpart F—Ground-Water Monitoring

§ 265.90 Applicability.

(a) Within one year after the effective date of these regulations, the owner or operator of a surface impoundment, landfill, or land treatment facility which is used to manage hazardous waste must implement a ground-water monitoring program capable of determining the facility's impact on the quality of ground water in the uppermost aquifer underlying the facility, except as § 265.1 and paragraph (c) of this Section provide otherwise.

(b) Except as paragraphs (c) and (d) of this Section provide otherwise, the owner or operator must install, operate, and maintain a ground-water monitoring system which meets the requirements of § 265.91, and must comply with §§ 265.92–265.94. This ground-water monitoring program must be carried out during the active life of the facility, and for disposal facilities, during the post-closure care period as well.

(c) All or part of the ground-water monitoring requirements of this Subpart may be waived if the owner or operator can demonstrate that there is a low potential for migration of hazardous waste or hazardous waste constituents from the facility via the uppermost aquifer to water supply wells (domestic, industrial, or agricultural) or to surface water. This demonstration must be in writing, and must be kept at the facility. This demonstration must be certified by a qualified geologist or geotechnical engineer and must establish the following:

(1) The potential for migration of hazardous waste or hazardous waste constituents from the facility to the uppermost aquifer, by an evaluation of:

(i) A water balance of precipitation, evapotranspiration, runoff, and infiltration; and

(ii) Unsaturated zone characteristics (i.e., geologic materials, physical properties, and depth to ground water); and

(2) The potential for hazardous waste or hazardous waste constituents which enter the uppermost aquifer to migrate to a water supply well or surface water, by an evaluation of:

(i) Saturated zone characteristics (i.e., geologic materials, physical properties, and rate of ground-water flow); and

(ii) The proximity of the facility to water supply wells or surface water.

(d) If an owner or operator assumes (or knows) that ground-water monitoring of indicator parameters in accordance with §§265.91 and 265.92 would show statistically significant increases (or decreases in the case of pH) when evaluated under § 265.93(b), he may, install, operate, and maintain an alternate ground-water monitoring system (other than the one described in §§ 265.91 and 265.92). If the owner or operator decides to use an alternate ground-water monitoring system he must:

(1) Within one year after the effective date of these regulations, submit to the Regional Administrator a specific plan, certified by a qualified geologist or geotechnical engineer, which satisfies the requirements of § 265.93(d)(3), for an alternate ground-water monitoring system;

(2) Not later than one year after the effective date of these regulations, initiate the determinations specified in § 265.93(d)(4);

(3) Prepare and submit a written report in accordance with § 265.93(d)(5);

(4) Continue to make the determinations specified in § 265.93(d)(4) on a quarterly basis until final closure of the facility; and

(5) Comply with the recordkeeping and reporting requirements in § 265.94(b).

§ 265.91 Ground-water monitoring system.

(a) A ground-water monitoring system must be capable of yielding ground-water samples for analysis and must consist of:

(1) Monitoring wells (at least one) installed hydraulically upgradient (i.e., in the direction of increasing static head) from the limit of the waste management area. Their number, locations, and depths must be sufficient to yield ground-water samples that are:

(i) Representative of background ground-water quality in the uppermost aquifer near the facility; and

(ii) Not affected by the facility; and

(2) Monitoring wells (at least three) installed hydraulically downgradient (i.e., in the direction of decreasing static head) at the limit of the waste management area. Their number, locations, and depths must ensure that they immediately detect any statistically significant amounts of hazardous waste or hazardous waste constituents that migrate from the waste management area to the uppermost aquifer.

(b) Separate monitoring systems for each waste management component of a facility are not required provided that provisions for sampling upgradient and downgradient water quality will detect any discharge from the waste management area.

(1) In the case of a facility consisting of only one surface impoundment, landfill, or land treatment area, the waste management area is described by the waste boundary (perimeter).

(2) In the case of a facility consisting of more than one surface impoundment, landfill, or land treatment area, the waste management area is described by an imaginary boundary line which circumscribes the several waste management components.

(c) All monitoring wells must be cased in a manner that maintains the integrity of the monitoring well bore hole. This casing must be screened or perforated, and packed with gravel or sand where necessary, to enable sample collection at depths where appropriate aquifer flow zones exist. The annular space (i.e., the space between the bore hole and well casing) above the sampling depth must be sealed with a suitable material (e.g., cement grout or bentonite slurry) to prevent contamination of samples and the ground water.

§ 265.92 Sampling and analysis.

(a) The owner or operator must obtain and analyze samples from the installed ground-water monitoring system. The owner or operator must develop and follow a ground-water sampling and analysis plan. He must keep this plan at the facility. The plan must include procedures and techniques for:

(1) Sample collection;
(2) Sample preservation and shipment;
(3) Analytical procedures; and
(4) Chain of custody control.

[*Comment:* See "Procedures Manual For Ground-water Monitoring At Solid Waste Disposal Facilities," EPA-530/SW-611, August 1977 and "Methods for Chemical Analysis of Water and Wastes," EPA-600/4-79-020, March 1979 for discussions of sampling and analysis procedures.]

(b) The owner or operator must determine the concentration or value of the following parameters in ground-water samples in accordance with paragraphs (c) and (d) of this section:

(1) Parameters characterizing the suitability of the ground water as a drinking water supply, as specified in Appendix III.

(2) Parameters establishing ground-water quality:

(i) Chloride
(ii) Iron
(iii) Manganese
(iv) Phenols
(v) Sodium
(vi) Sulfate

[*Comment:* These parameters are to be used as a basis for comparison in the event a ground-water quality assessment is required under § 265.93(d).]

(3) Parameters used as indicators of ground-water contamination:

(i) pH
(ii) Specific Conductance
(iii) Total Organic Carbon
(iv) Total Organic Halogen

(c)(1) For all monitoring wells, the owner or operator must establish initial background concentrations or values of all parameters specified in paragraph (b) of this Section. He must do this quarterly for one year.

(2) For each of the indicator parameters specified in paragraph (b)(3) of this Section, at least four replicate measurements must be obtained for each sample and the initial background arithmetic mean and variance must be determined by pooling the replicate measurements for the respective parameter concentrations or values in samples obtained from upgradient wells during the first year.

(d) After the first year, all monitoring wells must be sampled and the samples analyzed with the following frequencies:

(1) Samples collected to establish ground-water quality must be obtained and analyzed for the parameters specified in paragraph (b)(2) of this Section at least annually.

(2) Samples collected to indicate ground-water contamination must be obtained and analyzed for the parameters specified in paragraph (b)(3) of this Section at least semi-annually.

(e) Elevation of the ground-water surface at each monitoring well must be determined each time a sample is obtained.

§ 265.93 Preparation, evaluation, and response.

(a) Within one year after the effective date of these regulations, the owner or operator must prepare an *outline* of a ground-water quality assessment program. The outline must describe a more comprehensive ground-water monitoring program (than that described in §§ 265.91 and 265.92) capable of determining:

(1) Whether hazardous waste or hazardous waste constituents have entered the ground water;

(2) The rate and extent of migration of hazardous waste or hazardous waste constituents in the ground water; and

(3) The concentrations of hazardous waste or hazardous waste constituents in the ground water.

(b) For each indicator parameter specified in § 265.92(b)(3), the owner or operator must calculate the arithmetic mean and variance, based on at least four replicate measurements on each sample, for each well monitored in accordance with § 265.92(d)(2), and compare these results with its initial background arithmetic mean. The comparison must consider individually each of the wells in the monitoring system, and must use the Student's t-test at the 0.01 level of significance (see Appendix IV) to determine statistically significant increases (and decreases, in the case of pH) over initial background.

(c)(1) If the comparisons for the *upgradient* wells made under paragraph (b) of this Section show a significant increase (or pH decrease), the owner or operator must submit this information in accordance with § 265.94(a)(2)(ii).

(2) If the comparisons for *downgradient* wells made under paragraph (b) of this Section show a significant increase (or pH decrease), the owner or operator must then immediately obtain additional ground-water samples from those downgradient wells where a significant difference was detected, split the samples in two, and obtain analyses of all additional samples to determine whether the significant difference was a result of laboratory error.

(d)(1) If the analyses performed under paragraph (c)(2) of this Section confirm the significant increase (or pH decrease), the owner or operator must provide written notice to the Regional Administrator—within seven days of the date of such confirmation—that the facility may be affecting ground-water quality.

(2) Within 15 days after the notification under paragraph (d)(1) of this Section, the owner or operator must develop and submit to the Regional Administrator a specific plan, based on the outline required under paragraph (a) of this Section and certified by a qualified geologist or geotechnical engineer, for a ground-water quality assessment program at the facility.

(3) The plan to be submitted under § 265.90(d)(1) or paragraph (d)(2) of this Section must specify:

(i) The number, location, and depth of wells;

(ii) Sampling and analytical methods for those hazardous wastes or hazardous waste constituents in the facility;

(iii) Evaluation procedures, including any use of previously-gathered ground-water quality information; and

(iv) A schedule of implementation.

(4) The owner or operator must implement the ground-water quality assessment plan which satisfies the requirements of paragraph (d)(3) of this Section, and, at a minimum, determine:

(i) The rate and extent of migration of the hazardous waste or hazardous waste constituents in the ground water; and

(ii) The concentrations of the hazardous waste or hazardous waste constituents in the ground water.

(5) The owner or operator must make his first determination under paragraph (d)(4) of this Section as soon as technically feasible, and, within 15 days after that determination, submit to the Regional Administrator a written report containing an assessment of the ground-water quality.

(6) If the owners or operator determines, based on the results of the first determination under paragraph (d)(4) of this Section, that no hazardous waste or hazardous waste constituents from the facility have entered the ground water, then he may reinstate the indicator evaluation program described in § 265.92 and paragraph (b) of this Section. If the owner or operator reinstates the indicator evaluation program, he must so notify the Regional Administrator in the report submitted under paragraph (d)(5) of this Section.

(7) If the owner or operator determines, based on the first determination under paragraph (d)(4) of this Section, that hazardous waste or hazardous waste constituents from the facility have entered the ground water, then he:

(i) Must continue to make the determinations required under paragraph (d)(4) of this Section on a quarterly basis until final closure of the facility, if the ground-water quality assessment plan was implemented prior to final closure of the facility; or

(ii) May cease to make the determinations required under paragraph (d)(4) of this Section, if the ground-water quality assessment plan was implemented during the post-closure care period.

(e) Notwithstanding any other provision of this Subpart, any ground-water quality assessment to satisfy the requirements of § 265.93(d)(4) which is initiated prior to final closure of the facility must be completed and reported in accordance with § 265.93(d)(5).

(f) Unless the ground water is monitored to satisfy the requirements of § 265.93(d)(4), at least annually the owner or operator must evaluate the data on ground-water surface elevations obtained under § 265.92(e) to determine whether the requirements under § 265.91(a) for locating the monitoring wells continues to be satisfied. If the evaluation shows that § 265.91(a) is no longer satisfied, the owner or operator must immediately modify the number, location, or depth of the monitoring wells to bring the ground-water monitoring system into compliance with this requirement.

§ 265.94 Recordkeeping and reporting.

(a) Unless the ground water is monitored to satisfy the requirements of § 265.93(d)(4), the owner or operator must:

(1) Keep records of the analyses required in § 265.92(c) and (d), the associated ground-water surface elevations required in § 265.92(e), and

the evaluations required in § 265.93(b) throughout the active life of the facility, and, for disposal facilities, throughout the post-closure care period as well; and

(2) Report the following ground-water monitoring information to the Regional Administrator:

(i) During the first year when initial background concentrations are being established for the facility: concentrations or values of the parameters listed in § 265.92(b)(1) for each ground-water monitoring well within 15 days after completing each quarterly analysis. The owner or operator must separately identify for each monitoring well any parameters whose concentration or value has been found to exceed the maximum contaminant levels listed in Appendix III.

(ii) Annually: concentrations or values of the parameters listed in § 265.92(b)(3) for each ground-water monitoring well, along with the required evaluations for these parameters under § 265.93(b). The owner or operator must separately identify any significant differences from initial background found in the upgradient wells, in accordance with § 265.93(c)(1). During the active life of the facility, this information must be submitted as part of the annual report required under § 265.75.

(iii) As a part of the annual report required under § 265.75: results of the evaluation of ground-water surface elevations under § 265.93(f), and a description of the response to that evaluation, where applicable.

(b) If the ground water is monitored to satisfy the requirements of § 265.93(d)(4), the owner or operator must:

(1) Keep records of the analyses and evaluations specified in the plan, which satisfies the requirements of § 265.93(d)(3), throughout the active life of the facility, and, for disposal facilities, throughout the post-closure care period as well; and

(2) Annually, until final closure of the facility, submit to the Regional Administrator a report containing the results of his ground-water quality assessment program which includes, but is not limited to, the calculated (or measured) rate of migration of hazardous waste or hazardous waste constituents in the ground water during the reporting period. This report must be submitted as part of the annual report required under § 265.75.

ENVIRONMENTAL PROTECTION AGENCY

40 CFR Part 265

[SW-FRL 1999-2]

Standards for Owners and Operators of Hazardous Waste Disposal Facilities; Interim Rule

AGENCY: Environmental Protection Agency.

ACTION: Interim final amendments to rule.

SUMMARY: EPA is today promulgating, in interim final form, amendments to the ground-water monitoring standards for certain hazardous waste surface impoundments used to neutralize corrosive wastes. The amendments provide for a waiver of these standards for any surface impoundment that (1) Contains wastes which are hazardous only because they exhibit the corrosivity characteristic and contains no other hazardous wastes, and (2) is demonstrated to rapidly neutralize the wastes so that there is no potential for migration of any hazardous waste out of the impoundment.

The purpose of today's amendment is to relieve owners and operators of neutralization surface impoundments from having to monitor ground water in cases where such monitoring is not necessary to protect human health and the environment. Since the compliance date for the ground-water monitoring requirements is November 19, 1981, today's limited exception to those requirements is being made effective immediately.

DATE: Today's interim final amendments are effective January 11, 1982.

EPA will accept public comments on the proposed amendments until March 9, 1982.

ADDRESSES: Comments on the interim final amendments should be sent to Deneen Shrader, Docket Clerk, Office of Solid Waste (WH-562), U.S. Environmental Protection Agency, 401 M Street, SW., Washington, D.C. 20460. Comments should identify the regulatory docket as follows: "Docket No. 3004, Amendment of § 265.90(c)". Requests for a hearing should be addressed to John P. Lehman, Director, Hazardous and Industrial Waste Division, Office of Solid Waste (WH-565), U.S. Environmental Protection Agency, Washington, D.C. 20460.

The official docket for this regulation is located in Room 2636, U.S. Environmental Protection Agency, 401 M Street, SW., Washington, D.C. 20460 and is available for viewing from 9:00 a.m to 4:00 p.m., Monday through Friday, excluding holidays.

FOR FURTHER INFORMATION CONTACT: The RCRA hazardous waste hotline, Office of Solid Waste (WH-565), U.S. Environmental Protection Agency, 401 M Street, SW, Washington, D.C. 20460, 800/424-9346 (382-3000 in Washington, D.C.). For specific information on this amendment, contact Barry Stoll, Office of Solid Waste (WH-564), U.S. Environmental Protection Agency, 401 M Street, SW, Washington, D.C. 20460, (202) 755-9116.

SUPPLEMENTARY INFORMATION:

I. Purpose and Content of the Amendment

On May 19, 1980, EPA promulgated hazardous waste regulations in 40 CFR Parts 260-265 (45 FR 33066 *et seq.*) which established, in conjunction with earlier regulations promulgated on February 26, 1980 (45 FR 12721 *et seq.*), the principal elements of the hazardous waste management program under Subtitle C of the Resource Conservation and Recovery Act of 1976, as amended (42 U.S.C. 6921, *et seq.*). Part 265 of the May 19 regulations set forth standards applicable to owners and operators of hazardous waste treatment, storage, and disposal facilities during the "interim status" period. Subpart F (§§ 265.90-265.94) of those regulations established ground-water monitoring interim status standards applicable to land disposal facilities.

Section 265.90(c) provides that all or part of the groundwater monitoring requirements of Subpart F may be waived if the owner or operator demonstrates that there is a low potential for migration of hazardous waste or hazardous waste constituents from the facility via the uppermost aquifer to water supply wells or to surface water. The demonstration must be in writing and must be certified by a qualified geologist or geotechnical engineer and must establish the potential for migration of the hazardous waste or hazardous waste constituents from the facility to the uppermost aquifer and from that aquifer to water supply wells or surface water. This demonstration must be based on an evaluation of several hydrogeological factors set forth in the regulation.

As presently written, this self-implementing waiver provision is available only when hydrogeological factors reduce the migration potential to a low probability.[1] The regulation does not allow consideration of the disposed wastes' characteristics and the facility design to be used as a basis for reducing monitoring requirements. At the time that the regulation was promulgated, EPA was concerned that the state of knowledge about hazardous wastes and facility designs was not sufficiently certain to justify reductions in the basic monitoring system during interim status. (See 45 FR 33192, May 19, 1980.)

Since the time it promulgated § 265.90(c), EPA has become aware of one situation where it is appropriate to allow a waiver of ground-water monitoring requirements to be based upon consideration of the facility and the wastes disposed in the facility. Several industries operate surface impoundments which contain no hazardous wastes except corrosive wastes which themselves are hazardous only due to their corrosivity. In some cases, these wastes may be placed in the impoundment together with large volumes of non-hazardous wastes. In some of these cases, particularly where active mechanical mixing is performed in the impoundment, it may be reliably demonstrated that the corrosive wastes are neutralized shortly after being placed in the inpoundment. In such cases, there may be no potential for any hazardous wastes to migrate out of the impoundment.

For the neutralization surface impoundments described above, EPA believes that it makes little sense to monitor the ground water beneath the facilities. Therefore, EPA is amending § 265.90 to provide a waiver of Subpart F requirements for these types of facilities upon a demonstration that there is no potential for migration of hazardous wastes out of the facility. The demonstration would have to show, based on consideration of the corrosive wastes and the impoundment, that the corrosive wastes will be neutralized before they migrate out of the facility. The demonstration must be certified by a professional qualified to make this type of technical demonstration, rather than necessarily by a geologist or geotechnical engineer (as required in § 265.90(c)).

It may be that there are types of facilities other than neutralization surface impoundments for which reliable demonstrations can in some instances be made, based upon consideration of the nature of the wastes and of the facility, to show that there is no potential for migration of hazardous waste or hazardous waste constituents from the facility. EPA welcomes information (including detailed data) on such facilities.

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[1] As explained in the preamble to § 265.90(c) (45 FR 33192, May 19, 1980), a complete waiver of all Subpart F monitoring requirements is available only when the owner or operator can demonstrate that there is no potential for migration to water supply wells or surface water.

II. Promulgation of Today's Amendment in Interim Final Form

The compliance date for the existing Subpart F ground-water monitoring requirements is November 19, 1981. Unless today's amendment is promulgated and takes effect immediately, owners or operators of neutralization surface impoundments would be required to comply immediately with the Subpart F requirements even when they can demonstrate that those requirements are unnecessary to protect human health and the environment. Such a result would be contrary to the public interest. Therefore, EPA believes that good cause exists to promulgate today's amendment in interim final form without prior notice and comment.

EPA invites public comment on today's interim final rule. Consistent with its duty to fully consider all comments, EPA will promulgate a final rule as soon as possible after the close of the public comment period.

III. Effective date

Section 3010(b) of RCRA provides that EPA's hazardous waste regulations take effect six months after their promulgation. The purpose of this statutory requirement is to allow persons affected by the regulations sufficient lead time to comply with major new regulatory requirements. Today's amendment, however, does not impose a new requirement but rather relaxes an existing requirement. Therefore, the Agency believes it is consistent with the intent of Section 3010(b) to make today's amendment immediately effective.

IV. Regulatory Analysis

Section 3(b) of Executive Order 12291, 40 FR 13193 (February 19, 1981), requires EPA to initially determine whether a rule that it intends to propose or issue is a major rule and to prepare regulatory impact analyses for all major rules.

EPA has determined that the amendment being promulgated today is not a major rule. As discussed above, this amendment will allow a waiver of ground-water monitoring requirements under a limited set of circumstances. Accordingly, a Regulatory Impact Analysis is not being prepared for this amendment.

This regulation was submitted to the Office of Management and Budget for review as required by Executive Order 12291.

The information collection requirements in this interim final rule will be submitted to the Office of Management and Budget for clearance under the Paperwork Reduction Act of 1980. The information requirements or recordkeeping in this interim final rule will not take place until it has been cleared by the Office of Management and Budget. If OMB approves, the information collection requirements will take effect as set forth in this interim final rule. If not, EPA will revise the information requirements (and this rule if appropriate) to comply with OMB's determination.

Under the Regulatory Flexibility Act, 5 U.S.C. 601 *et seq.*, EPA is required to determine whether a regulation will have a significant impact on a substantial number of small entities so as to require a regulatory analysis. The additional waiver opportunity created by this amendment should, if anything, reduce the burden of compliance with the hazardous waste disposal regulations for small entities. Therefore, pursuant to 5 U.S.C. 605(b), I hereby certify that this rule will not have a significant adverse impact on a substantial number of small entities.

Dated: December 28, 1981.

Anne M. Gorsuch,
Administrator.

PART 265—INTERIM STATUS STANDARDS FOR OWNER AND OPERATORS OF HAZARDOUS WASTE TREATMENT, STORAGE, AND DISPOSAL FACILITIES

For the reasons set out in the preamble, Title 40 of the Code of Federal Regulations is amended as follows:

1. The authority citation for Part 265 reads as follows:

Authority: Secs. 1006, 2002(a), and 3004, Solid Waste Disposal Act, as amended by the Resource Conservation and Recovery Act of 1976, as amended (42 U.S.C. 6905, 6912(a), and 6924).

2. Section 265.90 is amended by adding paragraph (e) to read as follows:

§ 265.90 Applicability.

* * * * *

(e) The ground-water monitoring requirements of this Subpart may be waived with respect to any surface impoundment that (1) Is used to neutralize wastes which are hazardous solely because they exhibit the corrosivity characteristic under § 261.22 of this Chapter or are listed as hazardous wastes in Subpart D of Part 261 of this Chapter only for this reason, and (2) contains no other hazardous wastes, if the owner or operator can demonstrate that there is no potential for migration of hazardous wastes from the impoundment. The demonstration must establish, based upon consideration of the characteristics of the wastes and the impoundment, that the corrosive wastes will be neutralized to the extent that they no longer meet the corrosivity characteristic before they can migrate out of the impoundment. The demonstration must be in writing and must be certified by a qualified professional.

[FR Doc. 82-623 Filed 1-8-82; 8:45 am]

BILLING CODE 6560-30-M

Appendix B
USGS Information Contacts

wrd Water
Resources
Division

information guide

November 1980

U.S. Geological Survey

U.S. Department of the Interior
March 3 1849

HEADQUARTERS

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WATER RESOURCES DIVISION
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CHIEF HYDROLOGIST

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ASSOCIATE CHIEF HYDROLOGIST

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(Automatic Data Section)

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Room: 5B-332
Telephone: ext. 6879

NAWDEX PROGRAM OFFICE

Mail stop: 421
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NATIONAL WATER-USE INFORMATION PROGRAM

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Room: 5A-213
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SCIENTIFIC PUBLICATIONS SECTION

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SURFACE WATER BRANCH

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QUALITY OF WATER BRANCH

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NORTHEASTERN REGION

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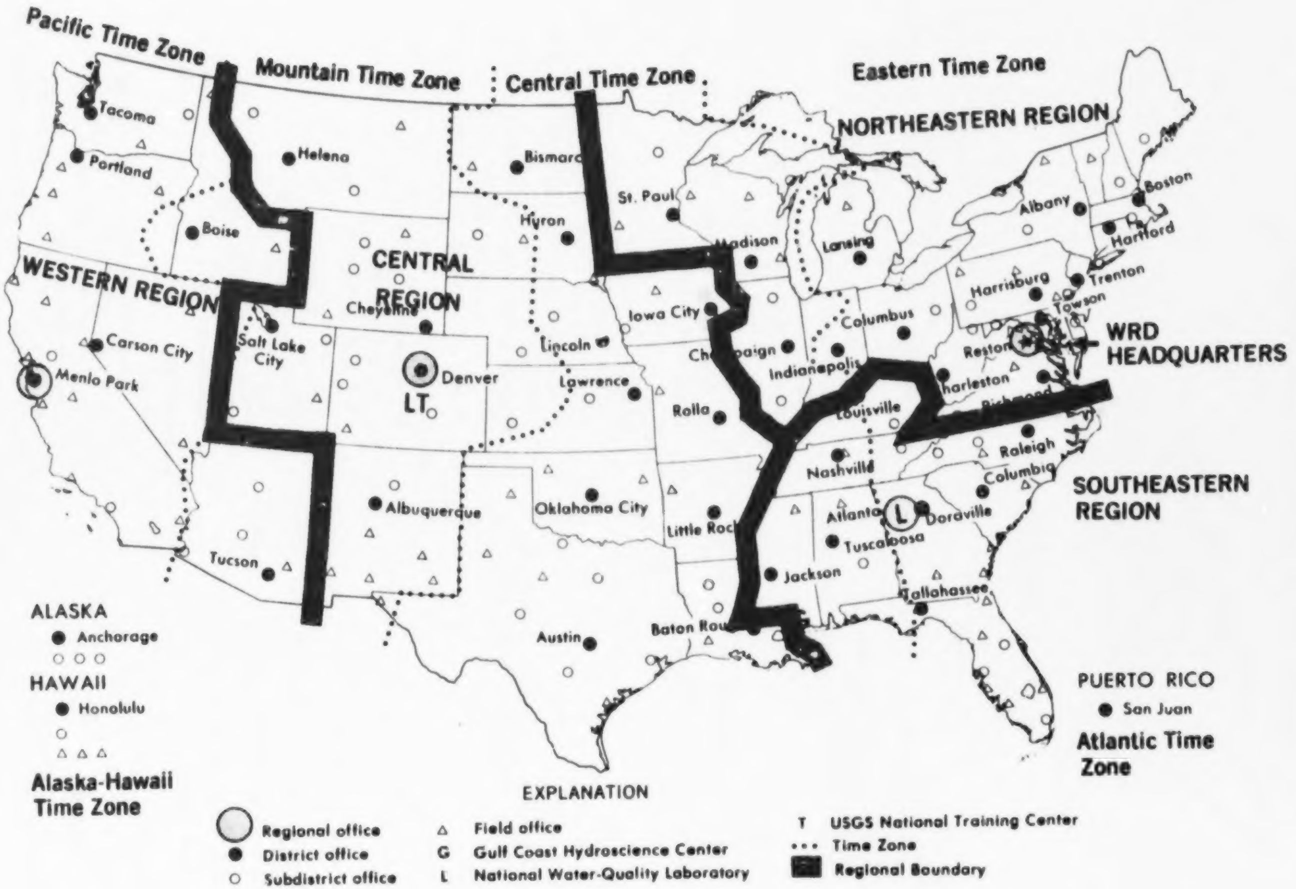
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APPENDIX C

EPA Interim Primary Drinking Water Standards

Parameter	Maximum level (mg/1)
Arsenic	0.05
Barium	1.0
Cadmium	0.01
Chromium	0.05
Fluoride	1.4-2.4
Lead	0.05
Mercury	0.002
Nitrate (as N)	10
Selenium	0.01
Silver	0.05
Endrin	0.0002
Lindane	0.004
Methoxychlor	0.1
Toxaphene	0.005
2,4-D	0.1
2,4,5-TP Silvex	0.01
Radium	5 pCi/1
Gross Alpha	15 pCi/1
Gross Beta	4 millirem/yr
Turbidity	1/TU
Coliform Bacteria	1/100 ml

(Comment: Turbidity is applicable only to surface water supplies)

Appendix D

EPA 600/4-81-056

TOTAL ORGANIC HALIDE (TOX)

Adapted From
Method 450.1

Interim

U S. Environmental Protection Agency
Office of Research and Development
Environmental Monitoring and Support Laboratory
Physical and Chemical Methods Branch
Cincinnati, Ohio 45268

November 1980

TOTAL ORGANIC HALIDE (TOX)

Method 450.1

1. Scope and Application

1.1 This method for the determination of Total Organic Halides as Cl^- by carbon adsorption specifies that all samples be run at least in duplicate. Under conditions of duplicate analysis, the reliable limit of sensitivity is 5 µg/L. Organic halides as used in this method are defined as all organic species containing chlorine, bromine and iodine that are adsorbed by granular activated carbon under the conditions of the method. Fluorine containing species are not determined by this method.

1.2 This is a microcoulometric-titration detection method applicable to the determination of the compound class listed above in drinking and ground waters.

1.3 This method is provided as a recommended procedure. It may be used as a reference for comparing the suitability of other methods thought to be appropriate for measurement of TOX (i.e., by comparison of sensitivity, accuracy and precision data).

1.4 This method should be used or supervised by analysts experienced in the operation of a pyrolysis/microcoulometer and in the interpretation of the results.

2. Summary of Method

2.1 A sample of water that has been protected against the loss of volatiles by the elimination of headspace in the sampling container, and is free of undissolved solids, is passed through a column containing 40 mg of activated carbon. The column is washed to remove any trapped inorganic halides, and is then pyrolyzed to convert the adsorbed organohalides to a titratable species that can be measured by a microcoulometric detector.

3. Interferences

3.1 Method interferences may be caused by contaminants, reagents, glassware, and other sample processing hardware. All of these materials must be routinely demonstrated to be free from interferences under the conditions of the analysis by running method blanks.

3.1.1 Glassware must be scrupulously cleaned. Clean all glassware as soon as possible after use by treating with chromate cleaning solution. This should be followed by detergent washing in hot water. Rinse with tap water and distilled water, drain dry, and heat in a muffle furnace at 400°C for 15 to 30 minutes. Volumetric ware should not be heated in a muffle furnace. Glassware should be sealed and stored in a clean environment after drying and cooling, to prevent any accumulation of dust or other contaminants.

3.1.2 The use of high purity reagents and gases help to minimize interference problems.

3.2 Purity of the activated carbon must be verified before use. Only carbon samples which register less than 1000 ng/40 mg should be used. The stock of activated carbon should be stored in its granular form in a glass container with a Teflon seal. Exposure to the air must be minimized, especially during and after milling and sieving the activated carbon. No more than a two-week supply should be prepared in advance. Protect carbon at all times from all sources of halogenated organic vapors. Store prepared carbon and packed columns in glass containers with Teflon seals.

3.3 This method is applicable to samples whose inorganic-halide concentration does not exceed the organic-halide concentration by more than 20,000 times.

4. Safety

The toxicity or carcinogenicity of each reagent in this method has not been precisely defined; however, each chemical compound should be treated as a potential health hazard. From this viewpoint, exposure to these chemicals must be reduced to the lowest possible level by whatever means available. The laboratory is responsible for maintaining a current-awareness file of OSHA regulations regarding the safe handling of the chemicals specified in this method. A reference file of material-handling data sheets should also be made available to all personnel involved in the chemical analysis.

5. Apparatus and Materials (All specifications are suggested. Catalog numbers are included for illustration only).

5.1 Sampling equipment, for discrete or composite sampling

5.1.1 Grab-sample bottle - Amber glass, 250-mL, fitted with Teflon-lined caps. Foil may be substituted for Teflon if the sample is not corrosive. If amber bottles are not available, protect samples from light. The container must be washed and muffled at 400°C before use, to minimize contamination.

5.2 Adsorption System

5.2.1 Dohrmann Adsorption Module (AD-2), or equivalent, pressurized, sample and nitrate-wash reservoirs.

5.2.2 Adsorption columns - pyrex, 5 cm long X 6-mm OD X 2-mm ID.

5.2.3 Granular Activated Carbon (GAC) - Filtrasorb-400, Calgon-APC, or equivalent, ground or milled, and screened to a 100/200 mesh range. Upon combustion of 40 mg of GAC, the apparent-halide background should be 1000-mg Cl^- equivalent or less.

5.2.4 Cerafelt (available from Johns-Manville), or equivalent - Form this material into plugs using a 2-mm ID stainless-steel borer with ejection rod (available from Dohrmann) to hold 40 mg of GAC in the adsorption columns. CAUTION: Do not touch this material with your fingers.

5.2.5 Column holders (available from Dohrman).

5.2.6 Volumetric flasks - 100-mL, 50-mL.

A general schematic of the adsorption system is shown in Figure 1.

5.3 Dohrmann microcoulometric-titration system (MCTS-20 or DX-20), or equivalent, containing the following components:

5.3.1 Boat sampler.

5.3.2 Pyrolysis furnace.

5.3.3 Microcoulometer with integrator.

5.3.4 Titration cell.

A general description of the analytical system is shown in Figure 2.

5.4 Strip-Chart Recorder.

6. Reagents

6.1 Sodium sulfite - 0.1 M, ACS reagent grade (12.6 g/L).

6.2 Nitric acid - concentrated.

6.3 Nitrate-Wash Solution (5000 mg NO_3^-/L) - Prepare a nitrate-wash solution by transferring approximately 8.2 gm of potassium nitrate into a 1-litre volumetric flask and diluting to volume with reagent water.

6.4 Carbon dioxide - gas, 99.9% purity.

6.5 Oxygen - 99.9% purity.

6.6 Nitrogen - prepurified.

6.7 70% Acetic acid in water - Dilute 7 volumes of acetic acid with 3 volumes of water.

6.8 Trichlorophenol solution, stock (1 µL = 10 µg Cl^-) - Prepare a stock solution by weighing accurately 1.856 gm of trichlorophenol into a 100-mL volumetric flask. Dilute to volume with methanol.

6.9 Trichlorophenol solution, calibration (1 µL = 500 ng Cl^-) - Dilute 5 mL of the trichlorophenol stock solution to 100 mL with methanol.

6.10 Trichlorophenol standard, instrument-calibration - First, nitrate wash a single column packed with 40 mg of activated carbon as instructed for sample analysis, and then inject the column with 10 µL of the calibration solution.

6.11 Trichlorophenol standard, adsorption-efficiency (100 µg Cl^-/L) - Prepare a adsorption-efficiency standard by injecting 10 µL of stock solution into 1 liter of reagent water.

6.12 Reagent water - Reagent water is defined as a water in which an interferent is not observed at the method detection limit of each parameter of interest.

6.13 Blank standard - The reagent water used to prepare the calibration standard should be used as the blank standard.

7. Calibration

7.1 Check the adsorption efficiency of each newly-prepared batch of carbon by analyzing 100 mL of the adsorption-efficiency standard, in duplicate, along with duplicates of the blank standard. The net recovery should be within 5% of the standard value.

7.2 Nitrate-wash blanks (Method Blanks) - Establish the repeatability of the method background each day by first analyzing several nitrate-wash blanks. Monitor this background by spacing nitrate-wash blanks between each group of eight pyrolysis determinations.

7.2.1 The nitrate-wash blank values are obtained on single columns packed with 40 mg of activated carbon. Wash with the nitrate solution as instructed for sample analysis, and then pyrolyze the carbon.

7.3 Pyrolyze duplicate instrument-calibration standards and the blank standard each day before beginning sample analysis. The net response to the calibration-standard should be within 3% of the calibration-standard value. Repeat analysis of the instrument-calibration standard after each group of eight pyrolysis determinations, and before resuming sample analysis after cleaning or reconditioning the titration cell or pyrolysis system.

8. Sample Preparation

8.1 Special care should be taken in the handling of the sample to minimize the loss of volatile organohalides. The adsorption procedure should be performed simultaneously on all replicates

8.2 Reduce residual chlorine by the addition of sulfite (1 mL of 0.1 M per liter of sample). Addition of sulfite should be done at the time of sampling if the analysis is meant to determine the TOX concentration at the time of sampling. It should be recognized that TOX may increase on storage of the sample. Samples should be stored at 4°C without headspace.

8.3 Adjust pH of the sample to approximately 2 with concentrated HNO_3 just prior to adding the sample to the reservoir.

9. Adsorption Procedure

9.1 Connect two columns in series, each containing 40 mg of 100/200-mesh activated carbon.

9.2 Fill the sample reservoir, and pass a metered amount of sample through the activated-carbon columns at a rate of approximately 3 mL/min. NOTE: 100 mL of sample is the preferred volume for concentrations of TOX between 5 and 500 µg/L; 50 mL for 501 to 1000 µg/L, and 25 mL for 1001 to 2000 µg/L.

9.3 Wash the columns-in-series with 2 mL of the 5000-mg/L nitrate solution at a rate of approximately 2 mL/min to displace inorganic chloride ions.

10. Pyrolysis Procedure

10.1 The contents of each column is pyrolyzed separately. After rinsing with the nitrate solution, the columns should be protected from the atmosphere and other sources of contamination until ready for further analysis.

10.2 Pyrolysis of the sample is accomplished in two stages. The volatile components are pyrolyzed in a CO_2-rich atmosphere at a low temperature to assure the conversion of brominated trihalomethanes to a titratable species. The less volatile components are then pyrolyzed at a high temperature in an O_2-rich atmosphere.

NOTE: The quartz sampling boat should have been previously muffled at 800°C for at least 2 to 4 minutes as in a previous analysis, and should be cleaned of any residue by vacuuming.

10.3 Transfer the contents of each column to the quartz boat for individual analysis.

10.4 If the Dohrmann MC-1 is used for pyrolysis, manual instructions are followed for gas flow regulation. If the MCT-20 is used, the information on the diagram in Figure 3 is used for gas flow regulation.

10.5 Position the sample for 2 minutes in the 200°C zone of the pyrolysis tube. For the MCTS-20, the boat is positioned just outside the furnace entrance.

10.6 After 2 minutes, advance the boat into the 800°C zone (center) of the pyrolysis furnace. This second and final stage of pyrolysis may require from 6 to 10 minutes to complete.

11. Detection

The effluent gases are directly analyzed in the microcoulometric-titration cell. Carefully follow manual instructions for optimizing cell performance.

12. Breakthrough

Because the background bias can be of such an unpredictable nature, it can be especially difficult to recognize the extent of breakthrough of organohalides from one column to another. All second-column measurements for a properly operating system should not exceed 10-percent of the two-column total measurement. If the 10-percent figure is exceeded, one of three events can have happened. Either the first column was overloaded and a legitimate measure of breakthrough was obtained - in which case taking a smaller sample may be necessary; or channeling or some other failure occurred - in which case the sample may need to be rerun; or a high, random, bias occurred and the result should be rejected and the sample rerun. Because knowing which event has occurred may not be possible, a sample analysis should be repeated often enough to gain confidence in results. As a general rule, any analyses that is rejected should be repeated whenever sample is available. In the event that the second-column measurement is equal to or less than the nitrate-wash blank value, the second-column value should be disregarded.

13. Quality Control

13.1 Before performing any analyses. the analyst must demonstrate the ability to generate acceptable accuracy and precision with this procedure by the analysis of appropriate quality-control check samples.

13.2 The laboratory must develop and maintain a statement of method accuracy for their laboratory. The laboratory should update the accuracy statement regularly as new recovery measurements are made.

13.3 It is recommended that the laboratory adopt additional quality-assurance practices for use with this method. The specific practices that would be most productive will depend upon the needs of the laboratory and the nature of the samples. Field duplicates may be analyzed to monitor the precision of the sampling technique. Whenever possible, the laboratory should perform analysis of standard reference materials and participate in relevant performance-evaluation studies.

14. Calculations

OX as Cl^- is calculated using the following formula:

$$\frac{(C_1 - C_3) + (C_2 - C_3)}{V} = \mu g/L \text{ Total Organic Halide}$$

where:

C_1 = µg Cl^- on the first column in series
C_2 = µg Cl^- on the second column in series
C_3 = predetermined, daily, average, method-blank value (nitrate-wash blank for a 40-mg carbon column)
V = the sample volume in L

15. Accuracy and Precision

These procedures have been applied to a large number of drinking-water samples. The results of these analysis are summarized in Tables I and II.

16. Reference

Dressman, R., Najar, G., Redzikowski, R., paper presented at the Proceedings of the American Water Works Association Water Quality Technology Conference, Philadelphia, Dec. 1979.

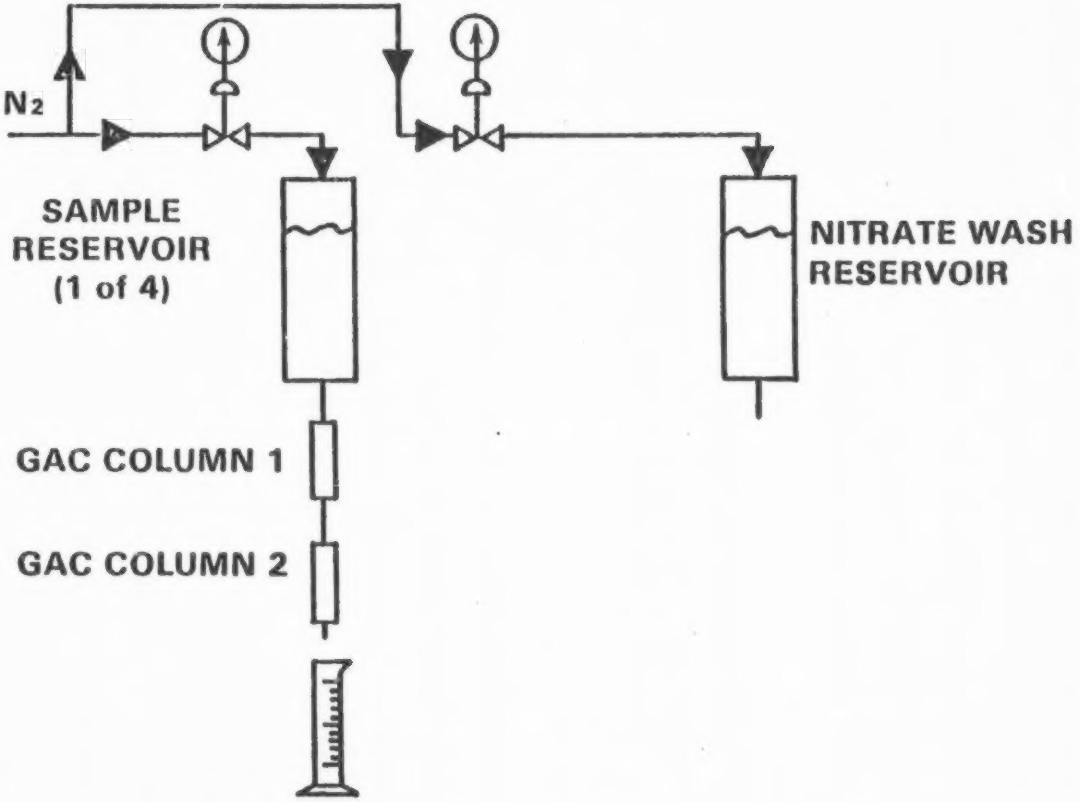
N2
SAMPLE RESERVOIR (1 of 4)
NITRATE WASH RESERVOIR
GAC COLUMN 1
GAC COLUMN 2

Figure 1. Adsorption Schematic

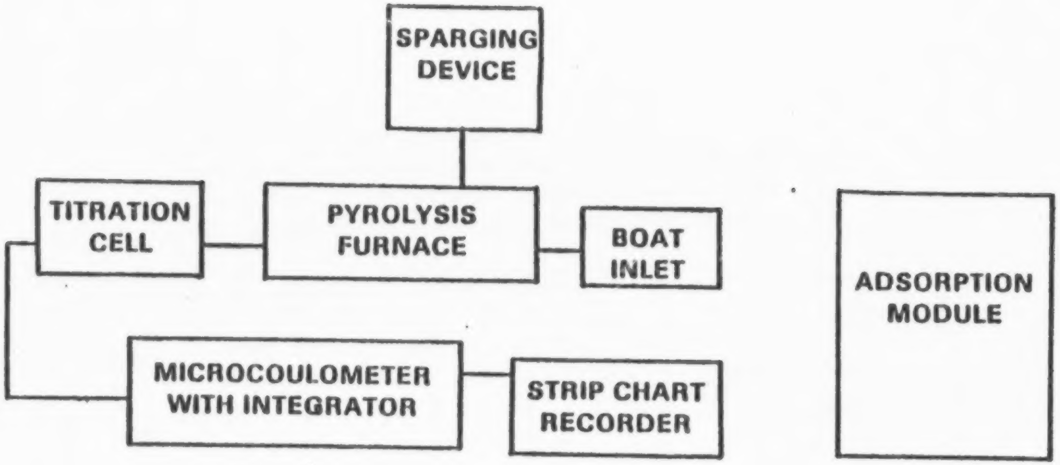
SPARGING DEVICE
TITRATION CELL
PYROLYSIS FURNACE
BOAT INLET
ADSORPTION MODULE
MICROCOULOMETER WITH INTEGRATOR
STRIP CHART RECORDER

Figure 2. CAOX Analysis System Schematic

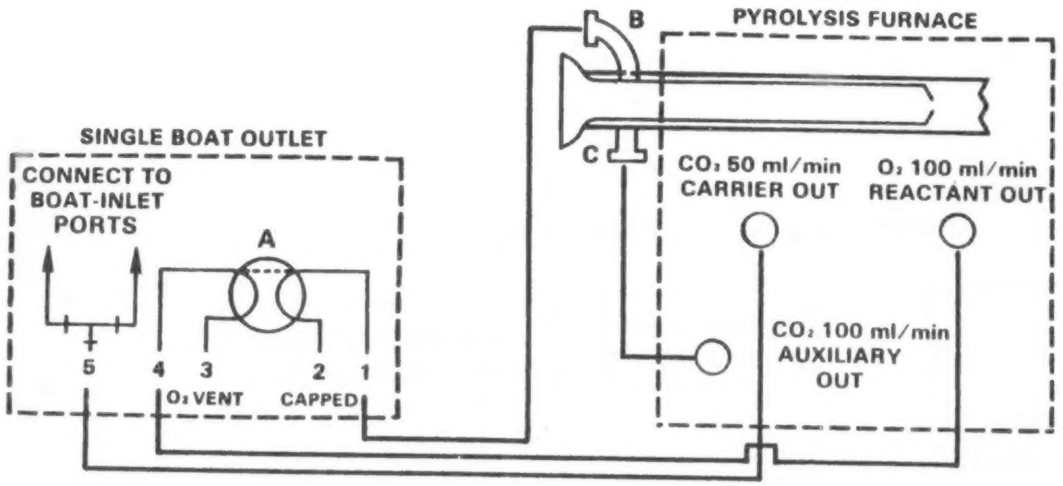
SINGLE BOAT OUTLET
CONNECT TO BOAT-INLET PORTS
A
5
4
3
2
1
O_2 VENT
CAPPED
B
C
PYROLYSIS FURNACE
CO_2 50 ml/min CARRIER OUT
O_2 100 ml/min REACTANT OUT
CO_2 100 ml/min AUXILIARY OUT

Figure 3. Rear view plumbing schematic for MCTS-20 system. Valve A is set for first-stage combustion, O_2 venting (push/pull valve out). Port B enters inner combustion tube; Port C enters outer combustion tube.

TABLE I

PRECISION AND ACCURACY DATA FOR MODEL COMPOUNDS

Model Compound	Dose µg/L	Dose as µg/L Cl	Average % Recovery	Standard Deviation	No. of Replicates
$CHCl_3$	98	88	89	14	10
$CHBrCl_2$	160	106	98	9	11
$CHBr_2Cl$	155	79	86	11	13
$CHBr_3$	160	67	111	8	11
Pentachlorophenol	120	80	93	9	7

TABLE II

PRECISION DATA ON TAP WATER ANALYSIS

Sample	Avg. halide ug Cl/L	Standard Deviation	No. of Replicates
A	71	4.3	8
B	94	7.0	6
C	191	6.1	4